1976-12-01

United States Great Lakes Shoreline Erosion Loadings

International Reference Group on Great Lakes Pollution from Land Use Activities

Great Lakes Basin Commission

Timothy J. Monteith

William C. Sonzogni

1976-12-01

United States Great Lakes Shoreline Erosion Loadings

International Reference Group on Great Lakes Pollution from Land Use Activities

INTERNATIONAL REFERENCE GROUP ON GREAT LAKES POLLUTION FROM LAND USE ACTIVITIES

INTERNATIONAL
JOINT
COMMISSION

UNITED STATES GREAT LAKES SHORELINE EROSION LOADINGS

U. S. GREAT LAKES
SHORELINE EROSION LOADINGS

Great Lakes Basin Commission
Ann Arbor, Michigan

by

Timothy J. Monteith
William C. Sonzogni

To be used as a portion of the Technical Reports of the International Reference Group on GREAT LAKES POLLUTION FROM LAND USE ACTIVITIES of the International Joint Commission--prepared in partial fulfillment of U.S. Environmental Protection Agency Contract No. 68-01-1598

3850

December, 1976

ACKNOWLEDGEMENTS

The authors wish to acknowledge the support of Mr. Eugene A. Jarecki, who served as the technical representative for the contract, and other staff members of the Great Lakes Basin Commission who contributed to the projects, particularly Gerald F. Kotas, Secretary to GLBC's Standing Committee on Coastal Zone Management. We also gratefully acknowledge the excellent work done by John M. Armstrong, Erwin Seibel, Cheryl L. Alexander and the other members of the University of Michigan staff in completion of their "Technical Report on Determination of Quantity and Quality of Great Lakes U.S. Eroded Material" (Subactivity 1-1b) which was a major source of information for this study. We wish to also thank them for their cooperation on this report.

A special thanks goes to those individuals who supplied information that was used in this report especially those listed below:

Donald Bahnick, University of Wisconsin - Superior
Parker Calkin, State University of New York at Buffalo
Charles Carter, Ohio Division of the Geological Survey
Mark Carter, U.S. EPA Central Regional Lab
Billy Fairless, U.S. EPA, Central Regional Lab
William Haras, Environment Canada
Charles Hess, University of Wisconsin, Geography Department
Martin Jannereth, Michigan Department of Natural Resources
William Mildner, U.S. Soil Conservation Service, U.S.D.A.
Robert Nugent, State University College, Oswego, New York
Fred Sullivan, U.S. EPA Region V
Michael Sydor, University of Minnesota, Department of Physics
Merle Tellekson, U.S. EPA Region V

DISCLAIMER

The study discussed in this Report was carried out as part of the efforts of the Pollution from Land Use Activities Reference Group, an organization of the International Joint Commission, established under the Canada-U.S. Great Lakes Water Quality Agreement of 1972. Funding was provided through the U.S. Environmental Protection Agency. Findings and conclusions are those of the authors and do not necessarily reflect the views of the Reference Group or its recommendations to the Commission.

TABLE OF CONTENTS

PAGE NO.

TABLE OF CONTENTS (continued)

PAGE NO.

LIST OF FIGURES

APPENDIX

LIST OF TABLES

LIST OF TABLES (continued)

SUMMARY

In order to make rational recommendations for managing different land resources in terms of their potential pollution to the Great Lakes, it is mandatory that the relative contributions and effects of <u>all</u> sources of pollution be established. This study provides an estimate of the total quantity and quality of material contributed to the lakes from shoreline erosion which has generally been previously ignored as a source of land-derived pollutants to the Great Lakes. It completes Subactivity 1-2 of U.S. Task D, Pollution from Land Use Activities Reference Group (PLUARG). The general background for this report was developed in Subactivity 1-1(a), in which samples from the U.S. Great Lakes shoreline were collected and analyzed for chemical characteristics, and Subactivity 1-1(b), in which the available information on Great Lakes shoreline erosion rates was compiled.

Average erosion along the U.S. Great Lakes shoreline is estimated to contribute about 40 million metric tons of material to the nearshore waters each year. This figure is about nine times greater than the preliminary PLUARG estimate of sediment contributed by U.S. tributaries as a result of sheet and gully erosion. The annual volume of material eroded is also estimated for maximum and minimum erosion conditions. During the last few years, high lake levels have promoted intensive coastal erosion so that current loadings of material from shoreline erosion may be closer to the maximum estimated loading rate of 70 million metric tons per year.

The volume of material eroded along the entire U.S. Great Lakes shoreline was calculated for over 1,300 small reaches and summarized on a county, planning subarea, lake basin, and total Great Lakes basis. The erosion volume was calculated based on recession rate, bluff height, and reach length. The computed erosion volume represents only the bluff erosion or that volume of material eroded from the elevated segment of the shoreline above the beach or beach terrace. Recession rate information was derived from the available literature which was compiled in Subactivity 1-1(b) of U.S. Task D, or from estimates made in this study based on extrapolation from known information.

Because of the large volume of material eroded from the bluffs along the U.S. Great Lakes shoreline, the loadings of some chemicals (total forms) associated with the eroded material are very high. For example, the estimated amount of total phosphorus contributed to Great Lakes as a result of average shore erosion conditions is about 9,000 metric tons per year. This figure is about the same as a preliminary PLUARG estimate of the total phosphorus loadings derived from sheet and gully erosion in the U.S. basin. Total phosphorus loadings from shoreline erosion vary according to geographic location, with Lake Superior receiving the largest total phosphorus loadings

from U.S. shoreline erosion.

Chemical loadings were estimated based on the volume of shoreline eroded and generalized chemical characteristics of the shoreline soils. In Subactivity 1-1(a) of Task D, shoreline samples were collected from 11 different counties along the U.S. Great Lakes shoreline and analyzed for physical and chemical characteristics, including particle size distribution, specific gravity, nutrients, pesticides, industrial organic pollutants, metals and other elements. These data are carefully evaluated and interpreted in this study. It was found that, for some parameters, there was a relationship between chemical concentrations and particle size distribution or soil texture. In general, clayey soils had higher chemical concentrations than sandy soils, and trends developed from these relationships were used to estimate chemical loadings for the whole U.S. shoreline.

In addition to data on the total amount of chemicals associated with erodible shoreline material, data on the biologically available fraction of the total was provided as a result of analysis of weak acid extracts of soil samples in Subactivity 1-1(a). These data are interpreted to provide a measure of the upper limit of biologically available concentrations. Loadings were thus calculated for "extractable" as well as total chemicals. In the case of phosphorus, the extractable phosphorus loadings are approximately 35-50 percent of the total phosphorus loadings.

The estimated sediment and chemical loadings from shore erosion in this report are only first approximations or order of magnitude estimates. The estimated loadings are intended primarily to show the relative magnitude of shore erosion loadings, particularly in comparison to other sources of sediment and chemicals to the Great Lakes.

The shore erosion process has been occurring for thousands of years along the Great Lakes and loadings from shoreline erosion must be considered a natural occurrence and not man-derived. Undoubtedly, large percentages of chemicals associated with the eroded shoreline material are rapidly lost to the lake sediments and do not interact to any degree with lake waters. Further, in some cases the eroded particulate material may actually remove dissolved constituents, such as phosphorus or heavy metals, from lake water through sorption or ion exchange processes. Nevertheless, that portion of the chemicals associated with erosion products that do become available to affect biological growth may be significant relative to other sources of biologically available chemicals. For example, the available phosphorus loading to Lake Superior from U.S. shore erosion is estimated to be in the same range as the reactive phosphorus contributed annually by both U.S. and Canadian tributaries to Lake Superior. Thus, despite the fact that shore erosion is a natural process, it is important to understand its impact so that the significance of other land-derived sources of pollutants, such as run-off can be put in proper perspective.

CONCLUSIONS

CONCLUSIONS

1. Shore erosion contributes a significant amount of sediment (solids) to the Great Lakes each year. Average shoreline erosion loading of sediment to the Great Lakes from the U.S. shoreline is estimated to be about 39 million metric tons. This figure is about nine times greater than the preliminary PLUARG estimate of sediment contributed by U.S. Great Lakes tributaries. The input of solids to the Great Lakes from shoreline erosion is also high relative to other sources of sediment, such as atmospheric inputs and point source inputs. Since erosion has been intensified as a result of high lake levels in recent years, current loadings of sediment may be closer to the maximum estimated loading rate, 70 million metric tons per year.

2. The amount of sediment contributed to the Great Lakes by shore erosion varies widely from one shoreline county to another. Leelanau County, Michigan (on Lake Michigan), contributes the largest total amount of sediment via shoreline erosion. Bayfield County, Wisconsin (on Lake Superior), contributes the next largest amount. In terms of loading per kilometer of shoreline, Allegan County, Michigan which borders Lake Michigan, has the highest loading rate. On a lake basis, Lake Michigan shorelines have the highest erosion rate per kilometer of shoreline, followed by Superior, Erie, Ontario, and Huron, respectively.

3. Because the rate at which any given shoreline reach will erode varies greatly from one year to the next, an average, maximum, and minimum erosion value likely to occur was generated for the entire U.S. Great Lakes shoreline. In general, the maximum erosion was between 4 and 6 times greater than the minimum erosion rate and was about twice as great as the average erosion rate.

4. The height of the erodible bluff appears to be the controlling physical feature affecting the volume of material eroded. A shoreline reach can have a very large recession rate, but if it has a low bluff height the amount of material contributed to the lake is relatively small. On the other hand, a reach of shoreline that has a very high bluff but a small recession rate can still contribute large amounts of material to the lake system.

5. Of the total average annual volume of shoreline material eroded into the Great Lakes, 53 percent was estimated to be sandy material, 34 percent was estimated to be loamy, and 13 percent was estimated to be clayey material. Lake Michigan shorelines were found to have the highest percentage of sandy soils while

Lake Superior shorelines were found to have the highest percentage of loamy and clayey soils.

6. Erosion volumes were calculated (on a reach by reach basis) based on recession rates, shore lengths, and bluff heights. Recession rates were obtained from; 1) Subactivity 1-1(b), in which erosion of each reach was derived from actual recession measurements (field measurements or aerial photo interpretation) or from; 2) estimates of recession made in this report for those reaches with no measured recession data. Approximately 44 percent of the erodible U.S. shoreline had recession information available based on actual measurements (field measurements or aerial photo interpretations). This same portion of shoreline contributed 66 percent of the total volume eroded from the U.S. shoreline as estimated in this report. Thus, even though the majority of U.S. erodible shoreline has no "measured" recession rate information, only 34 percent of the total volume contributed from U.S. Great Lakes shoreline erosion is based on these "estimated" recession rates. This indicates that data are available on those areas that contribute the most significant erosion loads.

7. Because of the large amount of sediment contributed to the Great Lakes from shoreline erosion, some effects on water quality are likely to occur, although little direct documentation of effects was found. Principal physical effects of eroded material are likely related to problems associated with turbidity and sediment accumulation. Turbidity would be most important in areas where the shoreline soils consist of finely divided particles such as in clay soils. In areas where the shoreline consists mostly of sand, the effect of turbidity may be relatively small since coarse grained sand particles settle rapidly. In general, shoreline erosion probably contributes larger sized soil particles to the Lakes than sheet erosion which would likely remove the finer sized particles. Further, surface soils are removed in sheet erosion while in shore erosion the entire profile is eroded.

8. Because of the large volume of material eroded from the bluffs along the U.S. Great Lakes shoreline, the loadings of the total forms of various chemicals associated with the eroded material is relatively high, at least for certain parameters. Undoubtedly, a large percentage of the chemicals associated with the eroded shoreline material is rapidly lost to the lake sediments and does not interact to any degree with lake waters. Further, the uptake by the eroded particulate material of constituents dissolved in lake waters, such as phosphorus or heavy metals, could be just as important environmentally as the release of contaminants. Nevertheless, despite the fact that the fraction of chemical that does become available to affect algal growth may be small relative to the total amount of chemical associated with the shoreline material, it may, in some cases, be significant relative to the biologically available chemicals contributed by other sources.

9. Based on the analysis of soil samples taken from Great Lakes shorelines, higher chemical concentrations of certain parameters, such as phosphorus, iron, manganese, and aluminum, can be expected in clay soils as compared to sandy soils. Thus, erosion of clay soil is likely to con-

tribute more total nutrients and other components to the lake than erosion of sandy soils.

10. Chemical concentrations found in shoreline soils were similar to concentrations found in other inland soils in the Great Lakes Basin. Chemical concentrations were highly variable from one location to another and, in some cases, even within a given shore profile, but this is expected when considering diverse soil systems.

11. The total phosphorus contributed to the Great Lakes by the annual average shoreline erosion is similar and in some cases greater than estimates of total phosphorus loadings from the tributaries. Lake Superior shore erosion contributes several times more total phosphorus than the total tributary phosphorus input from both the U.S. and Canada. Lake Michigan shorelines contribute about the same average amount of phosphorus annually from erosion as is contributed by Lake Michigan tributaries. Lakes Huron, Ontario, and Erie have shoreline erosion phosphorus inputs that are somewhat less than the tributary inputs. These comparisons are based on average annual shoreline erosion rates. Overall, it appears that shoreline erosion can contribute on the order of 25 percent of the total phosphorus loadings from all U.S. sources to the Great Lakes. This is about the same percentage of the total load as is contributed by tributary loadings. The average annual extractable (0.05 N HCl extraction) phosphorus loadings from shoreline erosion were about 45 percent of the average total phosphorus loadings for the entire U.S. shoreline. There is some variation for individual lake coastlines with Lake Superior shorelines having the highest ratio of extractable phosphorus loadings to total phosphorus loadings.

12. The Lake Superior shoreline contributes the most total phosphorus per kilometer of shoreline followed by Lakes Michigan, Erie, Ontario, and Huron shorelines, respectively. This is indicative of the fact that a large percentage of the Lake Superior shoreline is composed of clay materials which were found to be generally high in phosphorus content compared to sandy soils. Iron County, Wisconsin, Lake Superior, has the highest phosphorus loading rate, followed by Douglas County, Wisconsin, Lake Superior.

13. It is estimated that the available phosphorus loading to Lake Superior lies within the range of 80 to 2000 metric tons per year. This loading is significant relative to other available nutrient sources to Lake Superior. For example, shore erosion may be contributing about the same order of magnitude of available phosphorus as is derived from tributary loadings to Lake Superior. Insufficient data are available for other lakes to determine a possible range of available phosphorus. However, an upper limit to phosphorus availability is provided by extractible phosphorus loadings. Since solution concentrations in the other Great Lakes, particularly the lower lakes, are higher than Lake Superior and because the shorelines of other lakes contain less clayey material, the amount of available phosphorus contributed by shoreline erosion in these lakes is likely to be a smaller proportion of the total phosphorus than found for Lake Superior. However, if the eroded material is subject to certain environmental conditions, such as anoxia which occurs in the central basin of Lake Erie, a

release of available phosphorus from eroded shoreline material could con-conceivably occur.

14. The estimated nitrogen loadings to the Great Lakes from shoreline erosion were judged to be small relative to nitrogen loadings from other sources. Organic carbon loadings were estimated but no conclusions could be reached from the data. Silica was not measured in this study, but because silica is a major component of soils, particularly sandy soils, the total contribution would be expected to be relatively large. The fraction of this silica that becomes available for diatom growth is unknown, however.

15. In general, metals associated with eroded shore materials were not judged to be important as a source of pollutants to the Great Lakes. While levels of the total forms of some metals may be significant relative to other sources, the amount of the total metal that is available to biota is probably low. Anthropogenic sources of metals have undoubtedly a much more important influence on Great Lakes water quality. Highest loadings of metals would probably be found in areas of the shoreline with high clay content, such as the red clay area of the Lake Superior coastline. Total loadings of iron and manganese appear to be significant relative to estimated total tributary loadings for Lake Huron and Lake Superior. (Data for comparison is not available for the other lakes.)

16. Analysis of shoreline samples for trace pesticides and other trace organic contaminants revealed that concentrations of these parameters were quite low. Consequently, the loading of pesticides and other trace organic contaminants from shoreline erosion is, as might be expected, not likely to be quantitatively significant.

17. Sediment or chemical loadings from shoreline erosion developed in this report must be considered only as a first approximation or order of magnitude estimate. This report was designed to provide the relative magnitude of shoreline erosion loadings in order to determine whether shoreline erosion is a potentially significant source of pollution, particularly in comparison with other sources of pollution.

INTRODUCTION

PLUARG BACKGROUND

Both Canada and United States define the major activities under Task D of the Pollution from Land Use Activities Reference Group (PLUARG) as (1) assessment of shoreline erosion, (2) survey of river sediments and associated water quality and (3) assessment of the effects of river inputs on boundary waters. In April of 1975 a Plan of Study was developed to further define the United States portion of Task D. This Plan of Study posed the following general questions:

1) Is shore erosion a significant pollutant source to the lakes?

2) What is the tributary loading to the lakes that is attributable to land drainage, including the pollutant loading associated with river sediments?

3) How have river inputs derived from land drainage affected the lakes?

In order to answer the first question, Activity 1 of Task D, was broken down into two subactivities: 1-1 "Determination of Quantity and Quality of Eroded Material" and 1-2 "Overview Determination of Pollutant Loading from Shoreline Erosion".

Subactivity 1-1 consisted of two main parts. The first part (A) was the collection of samples from the U.S. Great Lakes shoreline and the subsequent chemical analysis of these samples. The second part (B) consisted of a technical report by the University of Michigan in which the quantity and quality of shoreline erosion was estimated for those shoreline reaches where data were available (Armstrong et al. 1976).

Subactivity 1-2, the subject of this report, is designed to provide an estimate of the total quantity and quality of material contributed to the lakes from shoreline erosion and to determine the importance of shoreline erosion as a potential source of pollution to the Great Lakes. In order to make rational recommendations for managing different land resources in terms of their pollution to the Great Lakes, it is mandatory that the relative contributions and effects of all sources of pollution be established in the PLUARG study. This study on shore erosion is, therefore, intended to provide PLUARG with a more complete understanding of the total loading of pollutants to the Great Lakes from all sources.

GREAT LAKES EROSION PROCESSES

On a geologic time scale, the Laurentian Great Lakes are a recent development.

INTRODUCTION

PLUARG BACKGROUND

Both Canada and United States define the major activities under Task D of the Pollution from Land Use Activities Reference Group (PLUARG) as (1) assessment of shoreline erosion, (2) survey of river sediments and associated water quality and (3) assessment of the effects of river inputs on Boundary waters. In April of 1975 a Plan of Study was developed to further define the United States portion of Task D. This Plan of Study posed the following general questions:

1) Is shore erosion a significant pollutant source to the lake?

2) What is the tributary loading to the lake that is attributable to land drainage, including the pollutant loading associated with river sediments?

3) How have river inputs derived from land drainage affected the lake?

In order to answer the first question, Activity 1 of Task D, was broken down into two subactivities: 1-1, "Determination of Quantity and Quality of Eroded Material" and 1-2 "Overview Determination of Pollutant Loading from Shoreline Erosion".

Subactivity 1-1 consisted of two main parts. The first part (a) was the collection of samples from the U.S. Great Lakes shoreline and the subsequent chemical analysis of these samples. The second part (b) consisted of a technical report by the University of Michigan in which the quantity and quality of shoreline erosion was estimated for those shoreline reaches where data were available (Armstrong *et al*. 1976).

Subactivity 1-2, the subject of this report, is designed to provide an estimate of the total quantity and quality of material contributed to the Lakes from shoreline erosion and to determine the importance of shoreline erosion as a potential source of pollution to the Great Lakes. In order to make rational recommendations for managing different land resources in terms of their pollution to the Great Lakes, it is mandatory that the relative contributions and effects of all sources of pollution be established in the PLUARG study. This study on shore erosion is, therefore, intended to provide PLUARG with a more complete understanding of the total loading of pollutants to the Great Lakes from all sources.

GREAT LAKES EROSION PROCESSES

On a geologic time scale, the Laurentian Great Lakes are a recent development.

The present configuration and outlets of the Lakes probably date back less than 5,000 years. Because of the relatively young geologic age of the area many dynamic processes are still occurring at a rapid rate. The erosion of the Great Lakes shoreline is an example of one of these processes.

The Great Lakes shoreline is composed of a variety of materials, many of which are unable to withstand wind and wave attack. Unconsolidated glacial tills, sands, silts and clays are the most commonly eroded materials found in the Great Lakes. Erodible bluffs and low plains occur along each of the Great Lakes in varying degrees. Lake Michigan has the greatest number of kilometers of this shore type and Lake Ontario the least. In other words, Lake Michigan has the most U.S. shoreline which is highly susceptible to erosion and Lake Ontario the least. The ability of the shoreline to withstand the destructive forces exerted by the water depends upon the composition of the shore front. The rocky coast of the Door Penninsula (Wisc.) possesses greater resistance to wave forces than do the sandy beaches of southwest Michigan or the silty clay bluffs of Ohio.

The prime cause of shore erosion is the energy released by waves and currents during high intensity wind storms. The shore material both above and below the still water level is loosened by the waves and removed by the currents. Under stable conditions the extracted material is restored by material deposited from the up-current direction. If this transported material (litoral drift) is interrupted, the extracted material is not replaced and erosion occurs. This process is intensified and magnified when the water level and/or the waves are high enough to enable the waves to act upon the higher land behind the beach. Removal of material then occurs at the toe of the bluff which is often composed of unstable materials. The bluff face becomes progressively steeper until the action of the wind, rain, and frost causes the material along the bluff face to slump. This slumped material then forms the new bluff toe and the process repeats itself. The rate of this entire process usually increases or decreases depending upon the levels of the lakes. At a high lake level it takes a much smaller storm to produce shoreline erosion.

Shoreline erosion, as used in this study is synonymous with the terms shore erosion, bluff erosion and bluffline erosion. These terms describe the total volume of material eroded from the elevated segment of the shoreline above the beach or beach terrace. For the purposes of this study, an eroding and accreting dunal terrace or beach is not considered to be a bluff. Once material is eroded from the bluff it is considered to be an input into the lake even though accretion of some of the eroded material can occur. The term shoreline recession (the linear movement of the bluffline landward) is also synonymous with the terms shore recession, bluff recession and bluffline recession, for the purposes of this report.

CANADIAN SHORELINE STUDIES

Concern by the Canadian Government over erosion on the Great Lakes and St. Lawrence system resulted in the formation in May of 1973 of a Federal Task Force on available information on shore erosion. The purpose of this task force was to assemble and assess all available information on shore erosion in the Canadian Great Lakes-St. Lawrence system to aid in Federal policy development. Under the aegis of the Task Force, the report "Shore Erosion in the Great Lakes-St. Lawrence System" (Brown et al., 1973) was compiled during the summer of 1973. This report is organized in three parts. Part 1, the summary, provides an overall description of shore erosion in the Canadian Great Lakes-St. Lawrence system and discusses its causes, magnitude, and economic effects. Part 2 provides a more detailed description of shore erosion on the Canadian Great Lakes and Part 3 compiles and analyzes erosion information on the Canadian St. Lawrence system.

All available information related to shore erosion on the Canadian shore of the Great Lakes as of the summer of 1973 was compiled and analyzed in Part 2 of this report. The causes of erosion are discussed and past studies and surveys relating to the Great Lakes shore erosion have been reviewed. Information obtained from these surveys and studies has been used to describe the Canadian Great Lakes shoreline and the flooding and erosion problems that occur there. Remedial measures against shore erosion damages are also reviewed.

Part 2 of this report also provides a summary of erosion problems and shore protection on the Canadian Great Lakes shoreline. Mileage figures for each of the Great Lakes and their connecting channels are given for various shore type classifications. The classifications are:

Noneroding,

Protected,

Critical significant erosion; and

Noncritical significant erosion.

Total mileage figures for the shoreline are also given. Of the 11,152 kilometers (6,931 miles) of Canadian shoreline with data, about 71 percent were found to be noneroding, three precent were protected, three precent had critical significant erosion and about 24 percent had noncritical significant erosion.

In October of 1975 a technical report was published entitled "Canada-Ontario Great Lakes Shore Damage Survey" (Bouldin, 1975). This report was the product of a study which began after extensive damages were incurred to the Canadian Great Lakes shoreline during the Fall of 1972 and Spring of 1973. Environment Canada and the Ontario Ministry of Natural Resources entered into an agreement to survey the nature and extent of these damages and to make preliminary recommendations related to shoreline management and planning. Acquisition of data on which these recommendations would be based commenced in the Spring of 1973 and was completed in the Summer of 1974.

Interpretation of aerial photos and other available information indicated Canadian shore damage was confined to the lower Great Lakes. Thus, the survey was restricted to the erodible portion of the Great Lakes from Port Servern on Georgian Bay to Gananoque on the Eastern end of Lake Ontario. Data were collected between November, 1972 and November, 1973 and included land use, land value, land ownership, shoreline physical characteristics, shore damage, and existing shore protection in damaged areas. These parameters, along with corresponding photomosaics and histograms of recession-accession rates, are depicted on a coastal zone atlas that accompanied this report. This atlas is a very detailed and elaborate document and is a major contribution to the shore erosion literature.

The shore damage survey concluded that from November, 1972 to November, 1973 almost 20 million cubic meters of material was eroded into Lakes Huron, St. Clair, Erie, and Ontario. The Canadian Lake Erie shoreline accounted for most of this volume, or about 88 percent of the total Canadian input to the Great Lakes. Lake Ontario supplied another eight percent, Lake Huron three percent, and Lake St. Clair had an input of approximately 0.5 percent. It should be emphasized that these values were based on only one year of erosion activity. Because water levels were extremely high at this time, these figures may not be representative of the average erosion situation on the Canadian shoreline over long periods of time, particularly during periods which include lower water levels.

U.S. SHORELINE STUDIES

In 1968, the 90th Congress authorized the National appraisal of shore erosion and shore protection needs. The resulting National shoreline study and the existing Federal shore protection program recognized beach and shore erosion as a problem for all levels of government. One of the reports that resulted from this study was the Great Lakes Region Inventory Report (U.S. Army Corps of Engineers, 1971). This report was a joint cooperative effort of various State and Federal agencies who were represented on the shore use and erosion work group for the Great Lakes Basin Commission's Framework Study.

This inventory report is an appraisal investigation intended only to define the order of magnitude of the regional shore erosion problems. A parallel study, The Shore Use and Erosion Appendix of the Great Lakes Basin Framework Study, (Great Lakes Basin Commission, 1975) considers future shore use and development in greater detail. The maps and basic data in both of these reports are the same.

One set of maps developed by the Army Corps was entitled Physical Description, Ownership, and Erosion and Flooding Problem Reaches (Great Lakes Basin Commission, 1975). This set of maps shows the Army Corps' breakdown of the shoreline into 10 different shore types. These types are:

- Artificial fill area
- Erodible high bluff, 30 ft. or higher
- Non-Erodible high bluff, 30 ft. or higher
- Erodible low bluff, less than 30 ft. high
- Non-erodible low bluff, less than 30 ft. high
- High sand dune, 30 ft. high
- Low sand dune, less than 30 ft. high
- Erodible low plain

- Non-erodible low plain

- Wetlands

Shore erosion and flooding problems are also classified on these maps by the severity of erosion or flooding which takes place over the different reaches. Shoreland erosion and flooding problems are classified as follows:

- Areas subject to erosion generally protected.

- Critical erosion areas not protected.

- Non-critical erosion areas not protected.

- Reaches of shore subject to lake flooding.

- Reaches of shore not subject to erosion or flooding.

The U.S. EPA analyzed soil samples from 11 representative counties for a large number of physical and chemical parameters in completion of Subactivity 1-1(a). In 1976 Armstrong et al. (1976) completed subactivity 1-1 (b) of Task D. The document they submitted for this subactivity contained all known reliable recession and erosion information available for the U.S. shoreline.

A study of Lake Erie shoreline erosion was conducted by the Ohio Division of Geological Survey (Carter, 1975). The quantity and chemical characteristics of material eroded into Lake Erie from the U.S. shoreline were estimated in this study.

Although there have been many studies of localized erosion problems in recent years (see Armstrong et al., 1976, for a review of the literature), the work under U.S. Task D of PLUARG (and the subject of this report) has been the only effort to examine the total U.S. shoreline erosion situation. This work has centered around Lakes Superior, Huron, Michigan and Ontario, relying on the information developed by Carter (1975) for an assessment of Lake Erie shore erosion.

GENERAL CHARACTERISTICS OF U.S. SHORELINE

Figure 1 shows the entire U.S. coastal zone. Demarkations have been made to differentiate the U.S. shoreline assigned to each lake. For example, the U.S. shoreline of Lake St. Clair was considered to be part of the total Lake Erie coastline. All the U.S. counties which border the Great Lakes are listed in Table 1. Identification numbers for the counties, assigned by the U.S. Army Corps of Engineers, are also included in this table.

A number of different statistics concerning the Great Lakes shoreline are summarized in Table 2. The shore distances (in kilometers) for each of the Corps of Engineers' shore type designations are given. Of the different shoretypes, the erodible low bluff shore type was most abundant followed by erodible plains. Over 70 percent of the 5,979 kilometers of Great Lakes shoreline is considered erodible according to Table 2. This is considerably different from the Canadian

FIGURE 1

U.S. GREAT LAKES SHORELINE

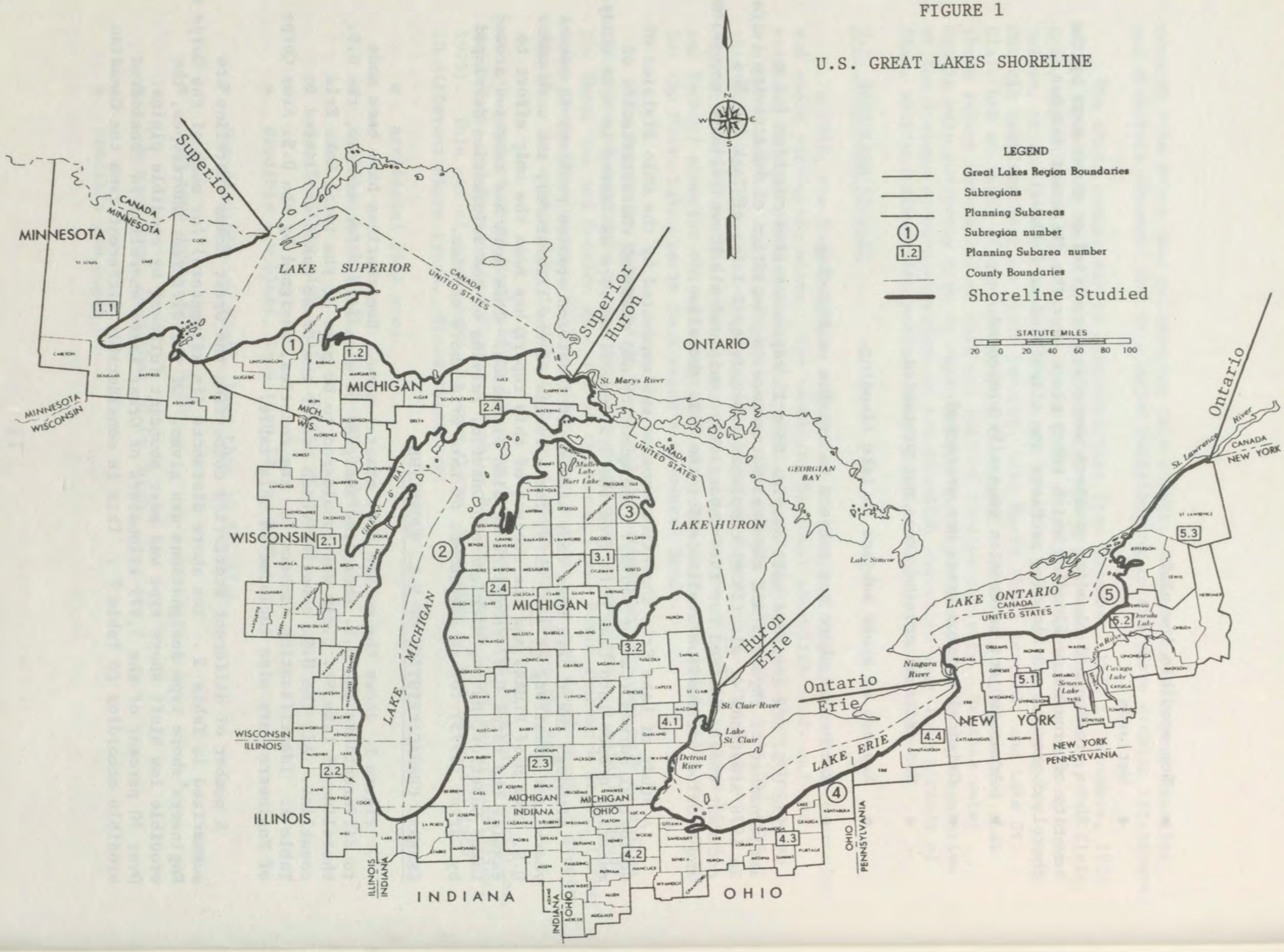


TABLE 1

U.S. ARMY CORPS COUNTY IDENTIFICATION NUMBERS

County	
Minnesota	
Cook County	1
Lake County	2
St. Louis County	3
Wisconsin	
Douglas County	4
Bayfield County	5
Ashland County	6
Iron County	7
Michigan	
Gogebic County	8
Ontonagon County	9
Houghton County	10
Keweenaw County	11
Baraga County	12
Marquette County	13
Alger County	14
Luce County	15
Chippewa County	16
Mackinac County	17
Schoolcraft County	18
Delta County	19
Menominee County	20
Berrien County	21
Van Buren County	22
Allegan County	23
Ottawa County	24
Muskegon County	25
Oceana County	26
Mason County	27
Manistee County	28
Benzie County	29
Leelanau County	30
Grand Traverse County	31
Antrim County	32
Charlevoix County	33
Emmet County	34
Wisconsin	
Marinette County	35
Oconto County	36
Brown County	37
Kewaunee County	38
Door County	39
Manitowoc County	40
Sheboygan County	41
Ozaukee County	42
Milwaukee County	43
Racine County	44
Kenosha County	45
Illinois	
Lake County	46
Cook County	47
Indiana	
Lake County	48
Porter County	49
La Porte County	50
Michigan	
Cheboygan County	51
Presque Isle County	52
Alpena County	53
Alcona County	54
Iosco County	55
Arenac County	56
Bay County	57
Tuscola County	58
Huron County	59
Sanilac County	60
St. Clair County	61
Macomb County	62
Wayne County	63
Monroe County	
Ohio	
Lucas County	65
Ottawa County	66
Sandusky County	67
Erie County	68
Lorain County	69
Cuyahoga County	70
Lake County	71
Ashtabula County	72
Pennsylvania	
Erie County	73
New York	
Chautauqua County	74
Erie County	75
Niagara County	76
Orleans County	77
Monroe County	78
Wayne County	79
Cayuga County	80
Oswego County	81
Jefferson County	82

TABLE 2

U.S. GREAT LAKES SHORE TYPES (kilometers)

Shore Type		Great Lakes	Lake Superior	Lake Michigan	Lake Huron[a]	Lake Erie[b]	Lake Ontario[c]
A	Artificial Fill Area (Non-Erodible)	305.6	9.8	108.5	5.0	159.1	23.2
HBE	High Bluff, Erodible	891.3	95.7	440.2	55.8	235.6	64.0
HBN	High Bluff, Non-Erodible	465.2	362.4	75.5	0.0	3.2	24.1
LBE	Low Bluff, Erodible	1,020.0	413.5	191.3	111.0	139.3	164.9
LBN	Low Bluff, Non-Erodible	597.6	273.7	39.7	103.0	9.8	171.4
HD	High Sand Dune	231.1	6.4	224.6	0.0	0.0	0.0
LD	Low Sand Dune	292.5	124.9	118.1	29.6	19.9	0.0
PE	Plain, Erodible	1,002.4	99.3	462.6	314.4	101.9	24.3
PN	Plain, Non-Erodible	392.0	37.6	279.2	73.0	2.1	0.0
W	Wetlands (Erodible)	675.6	44.1	152.0	364.0	58.7	56.8
W/PE	Wetlands/Plain, Erodible	89.0	0.0	83.4	0.0	5.6	0.0
W/LBE	Wetlands/Low Bluff, Erodible	16.4	0.0	16.4	0.0	0.0	0.0
Total Shoreline, U.S. Great Lakes		5,978.7	1,467.4	2,191.5	1,055.8[a]	735.3[b]	528.7[c]
Total Erodible Shoreline		4,218.3	783.9	1,688.6	874.8[a]	561.1[b]	310.1[c]
Total Lake Shoreline Without Connecting Rivers		5,583.2	1,467.4	2,191.5	909.1	550.3	466.0
Total Erodible Lake Shoreline without connecting Rivers		3,956.5	783.9	1,688.6	739.5	467.6	276.9

To Convert From	To	Multiply By
kilometers (km)	Miles (mi)	0.62114

[a] Includes St. Mary's River
[b] Includes St. Clair River, Lake St. Clair, Detroit River; does not include Sandusky Bay
[c] Includes Niagara River; does not include St. Lawrence River (243 km)

shoreline, where, as mentioned previously, only about 30 percent is considered to be erodible (Brown et al., 1973).

SPECIFIC OBJECTIVES OF SUBACTIVITY 1-2

The principal objective of this study is to determine whether shore erosion is likely to be a significant pollutant source to the Great Lakes. In order to accomplish this, the following specific tasks have been undertaken:

(1) Estimate the volume of material eroded and the resultant chemical loading for all U.S. Great Lakes shoreline.

(2) Determine the importance of the particulate and chemical loadings from shore erosion relative to other pollution sources.

(3) Assess the potential impact to the Great Lakes from any particulate or chemical pollution attributed to U.S. shore erosion.

Almost all past inquiries into shore erosion as a pollutant source have been directed toward the quantity rather than the quality (chemical content) of the shoreline material which is eroded. To be sure, both Canadian and U.S. studies indicate that shoreline erosion can be a significant source of particulate material or sediment to the lake. For Lake Erie, the input of particulate material has been estimated in recent studies to be a major source of sediment to the Lake (Carter, 1975; Kemp et al., 1976). In fact, it appears to be a more important source of particulate material than the tributaries, which in the case of Lake Erie, drain a large amount of agricultural land. Consequently, because of the large volumes being dealt with, the general chemical content of shoreline material eroded into the Great Lakes as well as the potential effect these materials may have on the Lakes is important.

Despite the fact that shoreline erosion may contribute large amounts of soil associated chemicals to the lakes, the biological availability (potential for uptake by algae or other biota) may be low. Consequently, even though large total quantities are involved, the chemical contribution from shoreline erosion may have little effect on the eutrophication of the lakes or their water quality in general.

Canadian studies indicate that erosion of unconsolidated bluffs along Lake Erie contribute mostly apatite phosphorus, a form which is relatively insoluble and apparently contributes little to the biological productivity of the Lake. Studies in the U.S. on the availability of pollutants associated with particulate material are also being made as part of PLUARG. Many questions are in need of answers. For example, does the amount of available phosphorus in erodible shoreline vary significantly depending on the location of the site sampled? Could the addition of particulate material from shore erosion in some cases actually remove soluble, biologically available phosphorus from the water (as a result of sorption or chemical equilibra reactions). Obviously, due to the size of the system being dealt with and the difference from site to site, research into this topic is only in its infancy. Nevertheless, for the purposes of PLUARG, this study attempts to provide a first cut assessment of the quantity and quality of shoreline erosion and how it may affect the Great Lakes.

ANALYSIS OF SHORELINE SAMPLES

SAMPLING PROCEDURES

In a cooperative effort between U.S. Army Corps of Engineers and the U.S. Soil Conservation Service, samples were collected from 49 U.S. Great Lakes shoreline profiles, for the purpose of determing the levels of nutrients, trace elements and other components in erodible lake shore materials. The sampline profiles were selected from 11 U.S. counties currently being assessed for shoreline damages by the Corps of Engineers. These profiles were intended to represent the different erosive conditions within the U.S. Great Lakes.

Sample Collection

Samples were collected by local organizations under contract to the U.S. Army Corps of Engineers during the months of May and June, 1975. Soil scientists from the Soil Conservation Service were made available to work with each sampling unit to help sample and describe the soil profile. In most cases samples were collected with the assistance of Soil Conservation Service personnel.

Composite samples were generally taken from each major soil horizon within the bluff. The number of samples needed to adequately sample the shoreline profile was determined, where possible, by a representative of the Soil Conservation Service. In most cases, composite samples were collected from each major soil horizon (A, B, and C). At least two or more samples from each bluff profile were obtained. Samples were obtained so as to be as representative as possible of unweathered material from the horizon which was sampled.

In some cases samples were obtained from both the top of the bluff and bluff face (only profiles within the State of Michigan). Samples from the top of the bluff were generally obtained by taking a vertical core sample. Samples from the face of the bluff were obtained by taking a horizontal core usually in the C horizon.

Descriptions of the bluff as well as the general characteristics of the soil were made in the field by the contractor and the representative of the Soil Conservation Service (if present). The description includes information on the profile sampled, the depth of the sample from the top of the bluff, whether the sample was taken from the face or the top of the bluff, the coordinates of the profile location, and a general account of the type of soil samples. This account included the soil texture, the pH of the soil, the type of boundary between horizons, and other appropriate information. Unfortunately, not all profiles were described in the same level of detail. Profiles from counties in the State of Michigan were usually described in greater detail than profiles from other states.

There were also more samples per profile from Michigan counties than normally found in other counties. Six out of 11 counties surveyed were in the State of Michigan and the majority of total samples obtained were also from this State so as a result most of the total profiles are fairly well described. In some cases, detailed maps were provided by the contractors collecting the samples which specified unique characteristics of the profile or the exact location of the profile. A summary of the available descriptions as well as the results of the chemical analyses of the samples is found in Appendix A .

Preservation and Storage

No special adjustments were made to preserve or store the samples from the time they were collected until the time they were shipped to the Central Regional Laboratory of the U.S. Environmental Protection Agency in October, 1975. Once at the EPA laboratory, samples were refrigerated (but not frozen). Since soil in the field is constantly exposed to the variable weather conditions found in the Great Lakes (freezing, thawing), it would be expected that no major changes would occur in the samples. However, it is reasonable to expect that some changes, in the chemical form or association of some species, although probably relatively small, may have occurred. For example, there may have been some conversion from soluble to particulate phosphorus or vice versa during the storage period. Since the object of this study was to get a general idea of the chemical loading of materials to the Great Lakes, any changes which might occur in the chemical composition of the material, whether chemical or biological, probably would not significantly affect the loading estimates.

ANALYTICAL METHODS

All analyses of shoreline samples were conducted by the Central Regional Laboratory of the U.S. Environmental Protection Agency, Region V. A brief description of the analytical techniques used, as provided by the U.S. Environmental Protection Agency, is given below. For more detailed information on the analytical techniques used, readers should consult "Methods for Chemical Analysis of Water and Waste" (EPA, 1974) or the Central Regional Laboratory of U.S. EPA directly.

Upon receipt at the Central Regional Laboratory, soil samples were refrigerated. Sample preparation consisted of mixing samples gently to insure that a representative aliquot could be taken. Three aliquots were taken for analysis.

Aliquot A was obtained from a mild acid extraction. This technique was used to provide an estimate of the concentration of "available" materials. One to two grams (dry weight basis) were added to 200 ml of 0.05N HCl in a 250 ml centrifuge tube. The mixture was shaken for two hours on a Burrell wrist action shaker and then centrifuged at approximately 25,000 g for 15 minutes. The decanated supernate was then used for analysis.

Aliquot B was dried at 105°C to a constant weight and the percent moisture calculated. The dried sample was used for all total parameter measurements. Aliquot C was air dried and used for particle size and specific gravity measurements.

Nutrient Parameters

Table 3 describes the parameters and analytical methods used for nutrients:

TABLE 3. PARAMETERS AND METHODS FOR NUTRIENT ANALYSIS OF SHORELINE SOIL SAMPLES

Parameter	Total	Extractable	Method
Ortho Phosphate-P		X	Combined single color reagent method (EPA, 1974)
Total Phosphorus	X	X	Kjeldahl digestion followed by combined single color reagent method (EPA, 1974)
Ammonia-N		X	Colorimetric phenate method (EPA, 1974)
Nitrate/Nitrite-N		X	Cadmium reduction method (EPA, 1974)
Total Kjeldahl N	X	X	Kjeldahl digestion followed by colorimetric phenate method
Total Organic Carbon	X	X	Persulfate oxidation followed by IR detection

Metal and Other Elemental Parameters

Two gram aliquots of the dried sample were passed through a #10 sieve and digested in 24 ml of 6 N hydrochloric acid for one hour, using a Technicon Block Digester at a digestion temperature of 100 $\pm$ 5°C. Samples were then diluted to 100 ml and either filtered or centrifuged (or both) to remove particulate matter. The solution was then analyzed for Ag, Al, B, Ba, Ca, Cd, Co, Cr, Cu, Fe, Mg, Mn, Mo, Ni, Pb, Sn, Ti, V, Y, and Zn using an inductively coupled argon plasma emission spectrometer. Detailed information on this method may be obtained from Ronan (1975). The solutions resulting from the mild acid extracts were aspirated directly into the emission spectrometer. Mercury was measured using flameless atomic absorption detection. Samples for total mercury were first digested by the automated method (EPA, 1974).

Some samples for metals were diluted (generally 1:10) prior to analysis. Consequently for some samples the reported detection limits were not always uniform for some of the parameters. The decision on dilution was based on the occurrence of major components (except calcium) at a concentration exceeding 5000 µg/g. According to EPA's Central Regional Laboratory, this procedure was used because of currently undocumented interference problems associated with the analytical method.

Trace Organic Parameters

Eight samples were extracted overnight in a soxhlet extractor using an acetone solvent. The extracts were concentrated to less than 20 ml, added to one liter of water and the waters back-extracted with 15% methylene choride in hexane. The hexane extracts were then dried and analyzed for trace organics by the standard semi-automated Central Regional Laboratory procedure using florisil and silicic acid liquid chromatography, followed by dual-column gas chromatography. Pesticides were separated from PCBs and other organics by eluting with different solvent mixtures in the standard fashion. More detailed information on the analytical techniques used for trace organic analysis may be obtained from the Central Regional Laboratory of the U.S. Environmental Protection Agency.

Physical Parameters

Aliquot C was used for determining the particle size distribution according to American Society for Testing and Materials (ASTM) procedure D422 (sedimentation cylinders). Large size particles were separated using the standard sieve procedure. Specific gravity was determined on Aliquot C using ASTM procedure D854-58. The percent total solids in each sample were determined from Aliquot B by drying at 105 °C to a constant weight.

Quality Control Statistics

Quality control data from the analysis of shoreline soil samples analyzed by U.S. EPA are given in Table 4. All statistics were provided by the Central Regional Laboratory of U.S. EPA.

Table 4 shows that there is a considerable range in the concentration of various Parameters found in the soil samples, as would be expected. The relative standard deviation of paired samples for total phosphorus was lower when the concentration range was greater than 100 mg/kg than when the range was less than 100 mg/kg. The relative standard deviation of paired samples for extractable phosphorus was quite low. The relative standard deviation of paired samples for nitrogen samples is reasonable considering the often encountered high variability of nitrogen analyses. The range in concentrations of metals and other experimental parameters is large, as can be seen in Table 4B. Generally, standard deviations of paired samples are given for two different concentration ranges when there was a large variability in concentration ranges.

One of the reasons for the large range in the concentration of trace elements in soil samples probably lies in the fact that high amounts of one or more common components in the soil can dilute out trace components. In other words concentrations in the solid phase (weight per weight) are not directly comparable to aqueous phase concentrations (weight per volume). This is because the reference in water is a constant while the reference in soil or sediment (the bulk material) has a variable composition. As an example, Bortleson and Lee (1974) have shown that most of the oligotrophic, unproductive lakes in northern Wisconsin have higher phosphorus concentrations in the sediments than the highly fertile, eutrophic lakes in the southern part of the State. Since lake sediments tend to

TABLE 4
QUALITY CONTROL DATA FROM SHORELINE SOIL SAMPLES
ANALYSIS CONDUCTED BY U.S. EPA

A. Nutrient Parameters

Parameter	Conc. Range, mg/kg	RSD*, %
Total Phosphorus	>100 mg/kg	26
Total Phosphorus	<100 mg/kg	34
Extractable Phosphorus	all	6
Total Kjeldahl Nitrogen	>100 mg/kg	27
Total Kjeldahl Nitrogen	<100 mg/kg	18
Extractable Kjeldahl Nitrogen	all	27

B. Metals and other Elemental Parameters (0.05N Hydrochloric Acid Extractable)

Parameter	Conc. Range, mg/kg	n	SD*, mg/kg
Ca	60-2500	9	59
	2500-4000	7	945
Mg	5-1000	10	32.7
	1000-6000	5	108
Na	5-100	15	2.5
Ag	Insufficient Data		
Al	5-50	7	1.5
	50-1000	9	29.2
B	1-4	14	0.17
Ba	0.5-4	8	0.15
	4-100	8	1.7
Be	0.3	3	0.02
Cd	0.5-1	15	0.07
Co	2	5	0.11
Cr	0.5	5	0.09
Cu	2	6	0.07
Fe	15-50	6	2.6
	50-400	9	8.7
Mn	0.3-50	10	0.49
	50-150	6	3.3
Mo	2	8	0.17
Ni	Insufficient Data		
Pb	3-25	3	1.5
Sn	Insufficient Data		
Ti	0.3-4	9	0.13
V	Insufficient Data		
Y	0.3-4	10	0.18
Zn	2-5	9	0.5

TABLE 4 (continued)

C. Metal and Other Elemental Parameters - 6N Hydrochloric Acid Digested

Parameter	Conc. Range, mg/kg	n	SD*, mg/kg
Ca	100-1500	18	119
	1500-7000	11	191
Mg	50-500	7	33.5
	500-5000	14	273
Na	10-50	20	7.8
	50-500	12	39.2
Ag	Insufficient Data		
Al	200-1000	18	45
B	1-10	15	0.74
	10-50	12	3.9
Ba	1-100	29	2.39
Be	Insufficient Data		
Cd	0.5	5	0.11
Co	1-20	16	1.06
	20-300	12	13.9
Cr	1-50	28	1.58
Cu	0.5-50	27	1.08
Fe	500-5000	17	239
Mn	10-100	17	3.4
	100-500	13	35
Mo	Insufficient Data		
Ni	Insufficient Data		
Pb	5-20	6	0.9
Sn	Insufficient Data		
Ti	40-1000	26	34
V	1-100	25	6.8
Y	Insufficient Data		
Zn	2-50	33	2.7

* RSD, Relative standard deviation of paired samples

SD, $\frac{mg}{kg}$ Standard deviation of paired samples be a sink for phosphorus (Sonzogni et al., 1976) it might be expected that the more fertile lakes would have higher sediment phosphorus concentrations. However, the northern lakes are soft water lakes with little calcium carbonate precipitation, while the southern lakes typically have very hard water and high rates of calcium carbonate precipitation. The calcium carbonate content of the sediment dilutes the phosphorus and other trace components so that the concentration on a weight per weight basis is less for the more productive lakes, even though the deposition rates of the trace elements may be higher. Thus, when interpreting shoreline chemical data, the effect of dilution by major constitutents on the trace element composition must be considered.

RESULTS OF ANALYSIS OF SHORELINE SAMPLES

Appendix A provides the results of the analysis of the samples collected from 49 different shoreline profiles in 11 counties. Included with this chemical and physical data are the narrative descriptions of the profiles based on the field notes provided by the agencies that obtained the samples.

No analyses were made on samples 153-3-1 through 153-3-4 in Schoolcraft County, Michigan due to either missing samples or to large rocks in the sample which made representative analysis impossible. Similarly, sample D33-3-8 in Chippewa County (Profile 2) and sample NY-3-4 in Oswego County (Profile 3) were not analyzed.

More detailed descriptions of the location of the profiles may be found in the Great Lakes Shoreland Damage Survey reports provided for the 11 counties surveyed (U.S. Army Corps of Engineers, 1976).

Table 5 compares the concentration ranges of several parameters obtained from the analysis of the shoreline samples from this study with the concentration ranges found for different Great Lakes Basin soil samples reported in other studies. This table indicates that the concentrations obtained in the shoreline profile analyses are within the same range as other soils studied in the Basin. The concentrations of other parameters determined for the shoreline samples are also generally within the concentration range found for similar soils (Brady, 1974; Carter, 1975; Helmke et al., 1976; Sommers et al., 1975; Veatch, 1953 and Wilding and Logan, 1976). Thus, while there are significant variations in the concentrations reported from one shoreline sample to another, the concentrations do fall within the general ranges found for other soils in the basin.

Nutrient Parameters

Concentrations of total phosphorus, extractable total phosphorus, extractable ortho phosphorus, extractable ammonia nitrogen, extractable nitrite/nitrate nitrogen, total kjeldahl nitrogen, and total and extractable organic carbon are reported in Appendix A . Total phosphorus concentrations as shown in Table 5 ranged from 13-1400 µg/g P. In general, total phosphorus concentrations tend to be lowest in the shoreline soil samples taken from the eastern shore of Lake Michigan and from the western shore of Lake Huron.

TABLE 5. COMPARISON OF MEASURED CONCENTRATION RANGES FROM DIFFERENT STUDIES OF GREAT LAKES BASIN SOILS

Total P	Range, µg/g	n
Veatch (1953)	70-300	18
Wilding and Logan (1976)	208-1834	53
Carter (1975) (Hydrolyzable P)	36-681	20
This Study	13-1400	164
Total N	**Range, µg/g**	**n**
Wilding & Logan (1976)	336-11,508	53
This Study	9-3,600	164
Total Fe		
Veatch (195)	800-37,900	33
Carter (1975)	1100-57,900	20
This Study	468-49,900	164
Total Pb		
Carter (1975)	0-227	20
This Study	< 3-253	164

Extractable ortho phosphorus and extractable total phosphorus concentrations are generally very similar. Extractable phosphorus concentrations for most of the samples are less than 50 percent of the total phosphorus concentrations. However, for some samples (St. Louis County, Minnesota shoreline soils, for example) the extractable phosphorus concentrations are about as large as the total phosphorus concentrations.

Extractable nitrate/nitrite-N and extractable ammonia-N concentrations are generally low but variable. The highest nitrite/nitrate concentration is found in Racine County (sample number R-4-1) when a value of 60 µg/g N was found. The largest ammonia-N value, 36 µg/g N, is found in Douglas Profile 3 (sample number D-3-1). Many extractable ammonia values were below the detection limit for the analysis.

The range of concentrations reported for total Kjeldahl nitrogen obtained for the shoreline soils is shown in Table 4 . As would be expected when comparing diverse soil samples, there is a tremendous range in total N concentrations. The range was even greater for streambank samples analyzed for PLUARG (Wilding and Logan, 1976). Somewhat lower total N concentrations are prevalent from counties along eastern Lake Michigan and western Lake Huron. Organic carbon concentrations are also quite variable, again as would be expected. No trends in organic carbon concentrations are apparent from the data in Appendix A .

Metal and Other Elemental Parameters

A number of metals were measured although they are not included in Appendix A .

Silver, both total and extractable, was measured, but was always found to be below the detection limit, which was either 1 or 10 µg/g for total silver and 1 or 2 for extractable silver. The results for silver, however, should actually be disregarded as HCl extraction and digestion would precipitate rather than extract silver due to the formation of highly insoluble AgCl. Nickel was also measured, but not included in Appendix A . All total nickel samples were less than 5 or 50 µg/g except samples 153-3-1 through 153-3-4 (477 µg/g), sample SL-5-2 (148 µg/g), and sample R-4-3 (96 µg/g). All extractable nickel values were reported as less than 3, less than 5, or less than 10 µg/g. Total beryllium is not reported in Appendix A since all values were less than 1 or less than 10 µg/g depending on the dilution used. Similarly, extractable beryllium was found to be always less than 1 or less than 0.3 µg/g. Total mercury was analyzed but is not reported in Appendix A since all values were reported to be less than 0.1 µg/g except sample 063-7-2 (0.2 µg/g). Extractable mercury was not analyzed due to the low total values.

Calcium and magnesium concentrations reported in Appendix A show a wide variability. However, some of the samples from Lake Michigan and Lake Huron shorelines have lower concentrations than samples from other shorelines. Sodium concentrations are also quite variable and many of the samples report concentrations less than 250 µg/g. Higher values can be found for total sodium in St. Louis County and the Wisconsin counties. Extractable sodium is variable, but tends to be lowest in the Michigan counties.

The range of concentrations found for total iron is shown in Table 5 . The total iron concentrations reported for the shoreline samples show the same large range as other soil samples. Some counties have significantly lower concentrations than others, however, extractable iron is generally an order of magnitude less than total iron concentrations and displays similar variability from sample to sample.

Manganese concentrations in the shoreline soils do not exhibit as great a concentration range as iron, but the pattern over various shore profiles does seem to follow that of iron concentrations, as would be expected due to the similar chemistry of iron and manganese. Extractable manganese is also considerably less than total manganese but varies from sample to sample in a manner similar to total manganese.

Total and extractable aluminum also seem to vary among samples in a fashion similar to iron. Extractable aluminum tends to be an order of magnitude less than total aluminum concentrations. Titanium concentrations are again quite variable, although the Michigan counties tend to be lower in terms of titanium concentrations compared to the profiles from other counties. Extractable titanium is generally low, particularly relative to total titanium values.

Most total boron concentrations were reported to be below the detection limit, which is much higher than the detection limit for extractable boron. Consequently, extractable boron is frequently reported in Appendix A with concentrations generally less than 10 µg/g. Both total and extractable barium concentrations were measureable in a greater number of samples than boron concentrations. Barium concentrations tend to be highest in samples from the Minnesota and Wisconsin counties. Cadmium and cobalt concentrations were almost all reported as below detection limits. Chromium concentrations in the shoreline soils are also usually below the detection limit. Some high total chromium values were reported, however. The highest total chromium concentration is found in a Schoolcraft County sample (153-1-2). Copper concentrations are variable and many samples have concentrations of both total and extractable copper below the limit of analytical detection. The highest copper concentrations tend to be associated with the western shore of Lake Superior and some Lake Ontario shoreline samples.

Most of the total molybdenum concentrations were reported as less than 30 µg/g or less than 300 µg/g depending on the dilution used. Extractable values are all generally low and many of them were reported as below 2 or 5 µg/g. Most tin concentrations were reported to be below the detection limit which for total tin is less than 500 µg/g. Extractable tin generally is low, less than 3 µg/g or less than 10 µg/g. Sample R-1-2 (Racine County, Profile 1) has an extractable tin value of 32.7 ug/g. No trends are evident for molybdenum or tin.

With the exception of a few samples, most of the concentrations of vanadium in the shoreline soil samples are less than the detection limits for both total and extractable vanadium. Similarly, most of the yttrium concentrations were reported as below the detection limit. As shown in Table 5 total lead ranges from below detectability to over 200 µg/g, which is similar to the range reported by Carter (1975) in his analysis of Lake Erie shoreline samples. Extractable lead is generally below the detection limit, although some significant extrable lead concentrations are found in Racine County, Wisconsin. Total lead concentrations are also highest in this county. Zinc concentrations are variable as shown in Appendix A . No trends in zinc concentrations are apparent from the reported values.

Trace Organic Parameters

The following samples were analyzed for trace organic compounds: 001-1-1, 033-3-2, 033-4-4, 063-5-1, 063-9-2, SL-3-1, NY-3-5, and D-3-1. These samples were analyzed for: hexachlorobenzene, β-BHC, lindane, treflan, aldrin, zytron, isodrin, heptachlor epoxide, γ-chlordane, o,p-DDE, p,p'-DDE, o,p-DDD, o,p-DDT, p,p'-DDD, p,p'-DDT, carbophenothion, methoxychlor, mirex, aroclor 1016, aroclor 1248, aroclor 1254, aroclor 1260, dibutyl phthalate, diethyl hexyl phthalate. All organic parameters were reported below the detection limit of 1 µg/g.

Physical Parameters

Specific gravity and percent total solids results are presented in Appendix A . Specific gravity values range from a low of 1.79 to a high of 2.97, although most of the specific gravity values are in the range of 2.5 to 2.7. Percent total solids range from 99.8 to 67.4 percent with most of the values in the 80 and 90 percent range.

Results of particle size determinations are shown in Appendix B . As mentioned in the methods section, larger size particles were separated according to the standard sieve technique while sedimentation cylinders were used for the finer particle size classification. As can be seen from Appendix B , most of the samples consist of particles of relatively large size. This is indicative of the coarse sand size particles rather than clay size particles.

DISCUSSION OF RESULTS OF SHORELINE SAMPLE ANALYSIS

Chemical Concentrations Vs. Soil Texture

As discussed previously, there appears to be differences in the concentrations of some chemicals between some of the counties, particularly between counties in the State of Michigan compared to counties from Wisconsin, Minnesota, or New York. Since the counties sampled in the State of Michigan tend to have sandy shorelines relative to other Great Lakes shorelines, differences in soil texture could be a possible reason for concentration differences. In order to explore this observation, it was decided to determine the soil texture for each sample, based on the results of the particle size analyses.

Soil texture was determined according to the particle size analysis performed by U.S. EPA and shown in Appendix B . Particle size results were separated into three categories: greater than 40 μ (sand), 5 to 40 μ (silt) and less than 5 μ (clay) using the sedimentation cylinder method. This generally conforms with standard definitions of soil separates, although clay is often classified as being less than 2 μ and silt is classified as being from 2 to 50 μ. The classification as to sandy soils, loamy soils, or clayey soils was made by first using the standard graph which shows the relationship between class name of a soil and its particle size distribution (Brady, 1974) to get the basic soil textural class name (e.g., clay loam, silty clay, etc.) The soil texture was generalized further by grouping the soils into three categories - sandy, loamy and clayey- using the U.S. Department of Agriculture classification system as shown in Table 6. Appendix B shows particle size distribution and indicates whether the soil samples were classed as sandy, loamy or clayey.

Table 7 presents a summary of the soil texture classifications determined from the measured particle size distribution. The distribution among sandy, loamy, and clayey soils is given according to county and lake basin. Table 7 shows that for all the samples obtained, most were sandy and relatively few were classified as having a clayey texture. Counties along Lake Michigan, particularly within the State of Michigan, are quite sandy. Also, counties bordering Lake Huron are generally sandy, with very few clayey soils. Lake Superior has the greatest number of clayey soils, reflective of the red clay bluffs found in western Lake Superior.

It should be realized that there is a very wide variability in terms of particle size distribution for each of the three general soil textures. As seen in Table 6 , the class name of a soil and its particle size distribution is somewhat arbitrary. Also, as shown in Table 6, there are a much larger number of class names which are subdivided under the loamy soils category than either sandy soils or clayey soils. Thus, despite the grouping of soils into these three categories, these categories are still mixtures and may tend to go from one extreme to another.

TABLE 6. U.S. DEPARTMENT OF AGRICULTURE CLASSIFICATION SYSTEM FOR SOIL TEXTURE

Common Names	Texture	Basic Soil Textural Class Names
Sandy soils	Coarse	Sandy Loamy sands
Loamy soils	Moderately coarse	Sandy loam Fine sandy loam
	Medium	Very fine sandy loam Loam Silt loam Silt
	Moderately fine	Clay loam Sandy clay loam Silty clay loam
Clayey soils	Fine	Sandy clay Silty clay Clay

For example, a loamy soil can be either very clayey or very sandy. The classification used is quite broad, as a result a considerable variability in the characteristics of the soil samples would be expected.

Table 7. SOIL TEXTURE CLASSIFICATIONS OF THE SHORELINE SAMPLES BASED ON MEASURED PARTICLE SIZE DISTRIBUTION

	Number of Samples		
	Sandy	Loamy	Clayey
Superior			
St. Louis Co.	6	8	9
Chippewa Co.	14	0	0
Douglas Co.	0	2	6
Total	20	10	15
Huron			
Alcona Co.	9	0	0
Huron Co.	11	12	0
Total	20	12	0
Michigan			
Manistee Co.	7	7	1
Muskegon Co.	19	0	0
Schoolcraft Co.	20	0	0
Racine Co.	5	8	1
Brown Co.	4	1	2
Total	55	16	4
Ontario			
Oswego Co.	11	5	0
Great Lakes Total	106	43	19

Following the grouping of data according to soil texture, chemical parameters found in these soil groups were examined. Table 8 presents the mean concentrations of a number of chemical parameters arranged by soil texture (sandy, loamy, or clayey soil). As can be seen from this table, mean concentrations tend to increase from sand to clay soils for a number of parameters. Further, the variance is less for the grouped data for most of the parameters compared to the variability one would get from the ungrouped data. Standard deviations are still quite high for a number of parameters, but this would still be expected, considering the variability of the mineral and organic composition of the samples within the three textural classes.

The results of a number of samples were not used in calculating the statistics in Table 8 . Brown County, Wisconsin, samples were not used due to the lack of information needed for the computations at the time the calculations were made and the lack of general descriptive data concerning the profiles. Samples 121-3-2, 121-3-3, and 121-3-3 from Muskegon County, Michigan Profile number 2,were also

TABLE 8
RESULTS OF SOIL ANALYSIS GROUPED ACCORDING TO SOIL TEXTURE

Soil Texture	Total P			Extractable Total P			Total Kjeldahl Nitrogen			Total Magnesium		
	$\bar{X}$	S_x	n	$\bar{X}$	S_x	n	$\bar{X}$	S_x	n	$\bar{X}$	S_x	n
Sandy	103	109	90	52	68	91	166	340	93	4,134	7,218	93
Loamy	380	176	42	109	138	42	916	946	42	14,169	13,181	40
Clayey	386	100	16	316	108	14	308	159	16	16,188	6,807	16

Soil Texture	Extractable Magnesium			Total Iron			Extractable Iron			Total Manganese		
	$\bar{X}$	S_x	n	$\bar{X}$	S_x	n	$\bar{X}$	S_x	n	$\bar{X}$	S_x	n
Sandy	1,748	2,267	93	5,507	6,777	93	81	95	93	108	139	74
Loamy	3,988	3,667	43	17,393	8,197	42	179	232	41	420	180	40
Clayey	3,925	2,119	16	30,938	10,407	16	258	115	15	524	146	16

Soil Texture	Extractable Manganese			Total Aluminum			Total Calcium			Total Lead		
	$\bar{X}$	S_x	n	$\bar{X}$	S_x	n	$\bar{X}$	S_x	n	$\bar{X}$	Sx	n
Sandy	21	33	93	1,463	2,675	93	8,432	14,288	92	K5	-	-
Loamy	92	86	42	8,487	3,062	41	26,596	26,456	41	28	41	42
Clayey	98	53	16	17,631	6,941	16	24,628	16,838	16	18	5	16

where $\bar{X}$ = mean value ug/g
Sx = standard deviation
n = number of samples
K5 = Less than 5 ug/g

not used due to suspected sample contamination by the U.S. EPA analysts. The following samples were also omitted in arriving at the statistics for the parameters in Table 8 : total P (NY-2-1, 001-5-2, 153-4-2); extractable total P (001-5-2, R-1-2, D-2-1); specific gravity (121-3-1, SL-2-3); extractable iron (SL-1-4, SL-2-5); total calcium (SL-2-5) total manganese (033-2-2 through 033-3-7, 033-4-3, 063-4-3, 063-7-2, 101-4-1, 101-4-2, 101-5-1, 121-4-3, 121-7-2, 153-5-1, 153-5-2, 153-5-3, NY-2-3, NY-1-2). These samples were rejected because the data supplied by the analysts were illegible, the data was reported as below the detection limit, or the samples had unusually high or low concentrations for a particular parameter.

Referring again to Table 8 , it can be seen that the mean concentration of total and extractable total phosphorus is higher for clayey compared to sandy soils. For total phosphorus and for extractable phosphorus the standard deviation of the mean is larger than the difference between sandy and loamy or loamy and clayey soils. However, there does seem to be a significant difference between sandy and clayey soils. Total Kjeldahl nitrogen does not show the same increasing concentration as one proceeds from a sandy soil to a clayey soil. In fact, loam soils tend to be much higher in total nitrogen than clayey or sandy soils according to Table 8 . Standard deviations for total Kjeldahl nitrogen measurements are quite high, probably because of the diverse soil samples.

The specific gravity of the soils, as shown in Table 8 , do not vary significantly between the three soil textures. This is consistent with the fact that the average arable surface soil has a specific gravity of about 2.65 (Brady, 1974). Soils rich in organic matter are likely to have a somewhat lower specific gravity.

Both total and extractable iron display quite different mean concentrations between sandy, loamy, and clayey soils. The standard deviations are relatively high, but still a trend is clear. This is understandable since iron oxides tend to be associated with clay rather than sand materials. Total and dissolved manganese concentrations also tend to be higher in clayey than in sandy soils. However, there is little difference between loamy and clayey soils, although loamy soils tend to be higher in manganese than sandy soils. Manganese shows a relationship similar to iron. Extractable manganese is also higher in clayey soils compared to sandy soils, although loamy soils have the same mean concentrations as clayey soils.

Total and extractable aluminum follow the same pattern as iron and manganese. There is a distinct difference between the mean aluminum concentrations in sandy and clayey soils from the basic mineral composition of clay versus sand (quartz). Calcium is also higher in samples made of clayey soils compared to sandy soils, although loamy soils have about the same mean concentration compared to clayey soils. Standard deviations are quite high for total calcium.

Total organic carbon concentrations tend to be highest in loam soils, although the variability is typically high. It is reasonable that the greatest organic matter would be found in a loamy rather than in either a predominantly sandy or a predominantly clayey soil. Also, the method used for total organic carbon may underestimate the total organic carbon actually found in soils since the persulfate digestion method, which was used, may not release the more resistant humic materials (Wilding personal communication, 1975).

Differences in concentrations between the three soil textures are not as obvious for most of the heavy metals primarily because most concentrations were at or below detection limits which prevents meaningful comparisons. A possible exception is lead. Total lead does appear to be found in greater amounts in clayey relative to sandy soils (Table 8). Extractable zinc was also examined in detail. However, mean concentrations of zinc are not significantly different in any of the three soil groupings. Most other heavy metals do not have enough data above the detection limit to even consider calculating mean values for the three different soil types.

The main conclusion that can be obtained from Table 8 is that, at least for certain parameters, one can expect higher concentrations in clay soils than in sandy soils. Thus, erosion of clay soils is likely to contribute more nutrients and other components to the lake than erosion of sandy soils.

In order to substantiate the validity of the trends observed in Table 8, chemical analysis performed in other studies on various soil types have been grouped according to soil texture for comparison. The data used for this comparison are all from Great Lakes Basin soils and are thus subject to the general climate found in the Basin.

Tables 9 and 10 show mean concentrations of a number of different parameters grouped according to soil texture from eroding streambank soil samples collected as part of a PLUARG project (Wilding and Logan, 1976). Samples were obtained from the Canaseraga Watershed in New York, the Oatka Watershed in New York, the Menomonee Watershed in Wisconsin, and the Mill Creed Watershed in Michigan.

TABLE 9. MEAN NUTRIENT CONCENTRATIONS GROUPED ACCORDING TO SOIL TEXTURE FROM PLUARG STREAMBANK SOIL SAMPLES[1]

Soil Texture	n	Mean Concentration, µg/g Total P	Avail. P[2]	NO_3-N	TN
sandy	3	308	10.3	18.2	421
loamy	44	679	8.9	22.9	2475
clayey	6	894	14.5	58.5	3974
sandy (C horizon samples only)	2	304	2.6	23.8	304
loamy "	9	510	3.4	16.4	1124
clayey "	2	1077	20.8	104.9	5355

1. Raw Data collected by Wilding, 1976
2 Bray 1 extraction

TABLE 10. MEAN TOTAL ELEMENTAL CONCENTRATIONS OF SEVERAL PARAMETERS GROUPED ACCORDING TO SOIL TEXTURE FROM PLUARG STREAMBANK SOIL SAMPLES[1]

Soil Texture	n	Mean Concentration Al	($\mu g/g$) Fe	Mn	Ca
sandy	3	3,496	9,103	258	24,400
loamy	44	11,564	20,190	547	23,806
clayey	5	19,840	31,200	719	11,940

1 Raw data analyzed by U.S. EPA Central Regional Laboratory using same methods as described for shoreline sample analyses.

These samples were collected in an attempt to determine the quantity and quality of streambank erosion which utimately contributes suspended material to the Great Lakes themselves. Further information on collection of samples or sampling methods may be obtained from PLUARG. It should be mentioned that the soil textures were determined from measured particle size distribution.

In Table 9 mean nutrient concentrations from the streambank soil samples are given. Results are shown for the analysis of all samples taken (all horizons) and also for C horizon samples only. As can be seen a very large number of samples, mostly in the loamy category, were taken from the A or B horizon. For streambank erosion the upper horizons are likely to be more important as an input to streams.

The data in Table 9 indicate similar relationships between nutrients and soil texture as was found for the shoreline samples. Total phosphorus concentration increase from sandy to clayey soils just as was found for the shoreline samples. Available P, determined by the Bray 1 method (discussed in a following section which is similar but not the same as the 0.05 N HCl extraction), also tends towards higher values for soils with a larger clay content. Similar results are found for nitrate N and total nitrogen. Ammonia N was also measured on the streambank samples, but the trends are not clear and in fact many of the samples had ammonia concentrations below the detection limit. The highest ammonia concentration is found in a clayey soil.

Metals were also measured on a selected number of the streambank samples. Analyses were made by the U.S. EPA Central Regional Laboratory using the same techniques for total and available metals as was used for the shoreline samples. Table 10 shows the trends for concentrations between sandy, loamy, and clayey soils for several different parameters. Aluminum, iron and manganese all have higher concentrations in clayey soils compared to sandy soils, although calcium does not. There is a lot of variability in the concentrations within a given soil texture, especially for calcium. Shoreline samples exhibit similar variability (see Table 8).

Unfortunately, the distribution between sandy, loamy and clayey soils is not even and the mean concentrations for sandy or clayey soils are based on only a few samples. However, aluminum, iron and manganese concentrations do follow the same trend as was found for the shoreline samples and in fact the measured mean concentrations for the three different textures are about the same for both the shoreline and streambank studies. Extractable metals were also measured in the streambank samples but the trends between the three different soil textures are not as marked. Extractable aluminum and iron concentrations are higher in clayey compared to sandy soils, however. Many other metals were measured in the stream-bank study but concentrations are below detection limits.

Metal concentrations measured on the streambank samples are somewhat higher than was found for the shoreline samples as a comparison of Table 8 and Table 10 will show. The available phosphorus as measured by the Bray 1 extraction on the streambanks samples is considerably less than the measured extractable phosphorus on the shoreline samples. This may indicate that the extractable phosphorus measured for the shoreline samples is high relative to the amount that might be available to the aquatic environment. Although extractable nitrate is not shown in Table 8 , the concentrations in the shoreline samples are generally lower than the concentrations reported for the streambank samples in Table 9 .

Some data are available on the nutrient content of different soils from the Black Creek Study (Sommers et al., 1975), a study of a small creek tributary to the Maumee River and consequently Lake Erie). Table 11 shows some of these data for total nitrogen and phosphorus and extractable phosphorus measured by the Bray 1 method. The soil fraction for clayey soils tends to have higher concentrations of nitrogen and phosphorus than the less clayey soils. Also, results of analysis of the individual sand, silt, and clay fractions in Table 11 show that the clay fractions have significantly higher concentrations than the sand or silt fractions. The phosphorus values and nitrogen values reported in Table 11 are again somewhat higher than the concentrations found for the shoreline samples. However, the concentrations are similar to those reported for the streambank samples (Wilding and Logan, 1976) except that extractable phosphorus concentrations are closer to the concentrations found for the shoreline samples.

TABLE 11. ANALYSIS OF SOIL SIZE FRACTIONS FROM BLACK CREEK PROJECT[1] (μg/g)

Soil Texture	Soil Type	Fraction	% of Soil	Total N	Total P	Extract[2] P
loamy	Haskins loam	Whole Soil	100.0	1021	364	46
		sand	43.0	166	168	29
		silt	44.5	710	240	36
		clay	12.4	4406	1135	155
loamy	Morely clay loam	Whole Soil	100.0	1240	366	12.4
		sand	23.5	225	90	10.5
		silt	43.4	835	127	10.5
		clay	33.0	2165	739	16.1
loamy	Nappanee clay loam	Whole Soil	100.0	1557	706	44
		sand	28.9	182	399	21
		silt	41.6	972	335	34
		clay	29.5	3231	1109	75
clayey	Hoytville silty clay	Whole Soil	100.0	2969	1241	117
		sand	14.2	424	704	49
		silt	42.1	1794	756	102
		clay	43.7	4466	1364	166

1 Data from Sommers et al. (1975)

2 Bray I Method

The higher total phosphorus and total nitrogen concentrations in the Black Creek Watershed samples and PLUARG streambank samples compared to shoreline samples may reflect differences in fertilization practices. It is unlikely that the shoreline along the Great Lakes receives much or any applied fertilizer. There is no indication that any of the shore profiles sampled were farmed or in fact fertilized within the recent past.

In a classical study of Michigan soils, Veatch (1953) measured chemical concentrations for a number of different soils around the state. The total phosphorus concentrations from a variety of parent material soils, when grouped according to soil texture as done in Table 12, show an increasing concentration from sandy to clayey soils, again indicating higher phosphorus values in clayey relative to sandy soils.

As part of a study of trace elements in Lake Superior dredge disposal, concentrations of certain trace elements were measured in samples of red clay from the Wisconsin shore of Lake Superior (Helmke et al., 1976). In addition to total sediment concentrations, silt plus clay and clay fractions were analyzed for trace metal concentrations. In most cases the clay fraction tends to have the highest metal concentrations and it appears that most of the metals are associated with the clay fraction of the shoreline samples (Helmke et al., 1976). Elements measured included As, Ba, Ce, Co, Cr, Cs, Cu, Eu, Fe, Ga, Hf, Hg, K, La, Lu, Na, Rb, Sc, Sm, Tb, Th, U, Yb, and Zn.

TABLE 12. TOTAL PHOSPHORUS CONCENTRATIONS IN MICHIGAN SOILS FROM VEATCH (1953) GROUPED ACCORDING TO SOIL TEXTURE (PARENT MATERIAL ONLY)

Soil Texture	n	Total P µg/g
Sandy	3	100
Loamy	6	200
Clayey	6	400

Helmke et al. (1976) concluded from their data that the finest grain size fractions have the highest concentrations of each trace element from the shoreline soil samples that they analyzed. Therefore, they felt that sediments composed mostly of silt and clay will generally have high concentrations of trace elements while those containing a larger proportion of quartz (i.e., sand) are more coarse grained and have lower concentrations of the trace metals. This is consistent with the conclusion reached from the shoreline data obtained for this and other studies and seems to apply to some of the nutrients as well as the trace elements studied by Helmke et al. (1976).

A number of researchers have found that size fractionation of samples (i.e., separating samples according to soil texture) before analysis eliminates the large sample-to-sample variations that are often obtained when sediment samples are compared without prior grouping. (Williams et al., 1971; Bannerman, et al., 1974; Williams, et al., 1976). Obviously, there still is some variability in concentrations of different elements due to a number of different natural processes, but grouping into different particle size fractions is helpful in removing at least some of the variability (Helmke et al., 1976). If analysis had been made on specific fractions of the shoreline samples (e.g., analysis of the clay fraction and the silt fraction) it is likely that the variability in the results would have been reduced even less. Because the proportion of sand, silt and clay is still variable within the three major soil texture groupings used for the shoreline samples, there is still significant variability in the results. It seems likely, based on the soils literature as well as the results that are presented here, that if the clay fraction had been measured separately, the highest concentrations of many elements would have been concentrated within that size fraction.

The reason that the clayey soils tend to have higher concentrations of contaminants than sandy soils is related to the chemistry of the minerals, particularly the surface chemistry. Helmke et al. (1976) Jenne (1968),Lee (1970) and Stumm and Morgan (1970) have all reviewed the role of the hydrous oxides (oxides of iron, manganese, and aluminum) which often coat or are associated with clay minerals in the sorption (or desorption) of heavy metals, phosphorus and other substances. Hydrous oxides and organic matter tend to sorb ions by ion exchange mechanisms. This mechanism seems to be much more important than the incorporation of trace metals and other elements in the layered clay structure. Sand (mostly quartz) is even less likely to have trace metals associated with its crystalline structure than clay. Further, hydrous oxides and organic material does not tend to coat or associate with quartz minerals.

The finer grain size fractions in soils, then, tend to have the highest concentrations of contaminants. The hydrous oxides (iron, manganese and aluminum oxides) and the organic matter associated with the clay minerals of the soil are probably most responsible for the higher concentrations rather than the clay minerals themselves. Consequently, the sandy soils along the eastern shore of Lake Michigan should contain less trace metals and other chemicals (i.e. phosphorus) which tend to associate with hydrous oxides and organic material, compared to soils with higher clay contents, such as those along the western shore of Lake Superior. In nonclayey soils where hydrous oxides are present due to the geology of area (for example, iron deposits), high concentrations of contaminants might be found. Studies by Plumb and Lee (1975) have shown the importance of iron oxides which tend to be associated with taconite tailings derived from iron ore mining in northern Minnesota and which have been disposed of in Lake Superior. Interestingly, Plumb and Lee (1975) found that these tailings tend to show significant sorption capacity for metals such as copper, zinc and cadmium and for phosphates when added to Lake Superior waters as a result of sorption by coatings of hydrous metal oxides on the surface of the taconite mineral fragments. It is important to note that contaminants sorbed onto hydrous oxides associated with clay minerals may not be tightly bound. Thus, not only may clay soils have high concentrations of some chemicals, but the chemical contaminants associated with clayey soils are likely to be more readily available than chemicals in other soils. The question of biological availability will be discussed further in the next section.

Potential Biological Availability

Because one of the objectives of this study was to investigate whether eroded extraction performed in this study.

Sodium hydroxide extractable inorganic phosphate has been shown by Sagher et al. (1975) to provide an estimate of the fraction of lake sediment phosphorus that can be readily taken up by algae. Sagher et al. (1975) have found that the sodium hydroxide extractable fraction is a measure of the maximum amount of phosphorus available to algae over a several week period when the algae are exposed to lake sediments from the photic zone of phosphorus limited lake waters. Extraction of phosphorus using an anion exchange resin appears to simulate uptake of phosphorus by algae at low inorganic phosphorus concentrations (approximately 1 µgP/l. Thus, equilibration of sediment for a short time with an anion exchange resin is used to estimate the fraction of phosphorus available to algae on a short-term basis. Hence, it gives a measure of the readily or immediately available phosphorus in the sediment. Oxalate extractions have been used (Shukla et al., 1971) to extract metals associated with hydrous oxides such as iron and aluminum oxides. Citrate dithionite bicarbonate is a chelating resin and the extraction procedure is similar to that using an anion exchange resin. This approach has been used to simulate the release of metals to lake water where the solution concentration of metals is low, such as would be expected in the Great Lakes (Jenne et al., 1974).

Bannerman et al. (1974) measured the amount of dilute (1N) HCl extractable phosphorus in Lake Ontario sediments as part of a series of sequential extractions. They found that large amounts of inorganic phosphorus (up to 90%) were found in the dilute HCl extract from the glaciolacustine clay samples. They concluded however that the dilute HCl extractable fraction contained mainly apatite-P, based on the works of Williams and Mayer (1972) and Seyers et al. (1973). This fraction of phosphorus was found to be immobile, based on estimates of uptake of inorganic P in this fraction of sediment by algae (Sagher, 1974). This would indicate that the extractable phosphorus using dilute HCl is probably a high estimate of the amount of readily available phosphorus. It is important to realize that significant differences can occur in the amount of phosphorus extracted (Bannerman et al., 1974) using 1N HCl and the amount extracted from 0.05N HCl.

Williams et al. (1976) have also recently reported on the forms of phosphorus in Lake Erie sediments. They have provided estimates of apatite P, non-apatite inorganic P, and organic P. These three forms were operationally defined, based on an extraction procedure involving sequential extractions. The sum of the apatite-P, the non-apatite inorganic P and the organic P was found to be essentially the same (usually slightly less) as the true total phosphorus fraction. This fraction was present mainly in the fine grained sediments and was found to be related to the reactive iron content of the sediments. The apatite P was the fraction extracted with dilute HCl following the sequential extractions of non-apatite P and organic P in a manner similar to that used by Bannerman et al. (1974). Apatite P was thought to be unavailable to algae.

Unfortunately, due to different sequences in extractions and different HCl concentrations, the 0.05N HCl extractable phosphorus used in the shoreline sample analyses for this project is not directly comparable to the apatite P fraction defined in Williams et al. (1976) or Bannerman et al. (1974). It is likely that the 0.05N HCl extraction used in this study is less than the sum of the apatite-P and the non-apatite inorganic-P but probably greater than the non-apatite inorganic P determined in Williams et al. (1976). Thus, based on the current state of the art, the 0.05N HCl extraction performed by the U.S. EPA Central Regional Laboratory probably overestimates or provides an upper limit to the phosphorus potentially available to aquatic organisms. In the previous section several available phosphorus data were reported which were determined using the Bray 1 extraction method. This method is commonly used in the soils field and consists of extraction with 1N NH_4F in 0.03N HCl (Jackson, 1973). The greater strength acid used by the U.S. EPA Central Regional Laboratory will probably liberate somewhat more phosphorus from soil hydrous oxides than are normally released using the Bray 1 extraction.

As reported previously the extractable ortho phosphorus concentrations were almost always very similar to the extractable total phosphorus concentrations in the shoreline samples. This would indicate that most of the phosphorus in the dilute acid extractant was ortho phosphate.

Another technique utilized by some to measure availability of nutrients and other materials to biota in the aquatic environment is the bioassay technique. This technique basically involves exposing an organism or group of organisms to a particular form of contaminant and determing the response of the organism. There has been a considerable amount of research in this area in the past, including the provisional algal assay procedures (EPA, 1971). However, bioassay tests are often very dependent upon the experimental conditions used and often do not actually reflect true environmental conditions. They are also much more difficult and time-consuming to perform relative to chemical extraction methods. Ideally, a combination of chemical extraction and bioassay techniques should be utilized. Currently, there is research being carried out to relate chemical extraction techniques to bioassay techniques (Cowen, 1974; Sagher et al., 1975 ; Schroeder, 1976).

In summary, extraction methods, despite their inherent problems are relatively easy to perform and probably give at least a qualitative picture of the availability question. Perhaps the greatest value of the mild acid extraction is that the lack of extractable phosphorus or other substances generally is a good indication that few contaminants would be released from the soils to the aquatic environment. Currently, there is much research being conducted in this field. The question of biological availability of contaminants associated with particulate material continues to be one of the key problems facing the Pollution from Land Use Activities Reference Group and non-point source researchers in general.

Chemical Concentration versus Soil Horizon

Because samples were taken from different soil horizons within a given profile (where such horizons existed), it was thought that there may be a relation between chemical concentration and soil horizon. For example, one might suspect to find differences in the chemical content of certain substances (e.g., phosphorus) between the A horizon and the C horizon. However, no specific correlation between chemical concentrations and the different soil horizons was obvious. Table 14 gives mean total phosphorus concentrations grouped according to the A, B, and C horizon for sandy soils, loamy soils, and clayey soils. As can be seen, there does not appear to be any significant trends or differences in total P content between the different soil horizons. Thus, in calculating shoreline material contributes to the chemical pollution of the Great Lakes, an attempt was made to investigate the potential of chemical components in the soil to be dissolved in lake water and the potential of these components to be taken up by the biota of the lake. Data were provided from the analysis of weak acid extracts from the U.S. EPA soil samples. These extractable concentrations, as reported in Appendix A, were provided in an effort to get some idea of the type and quantity of contaminants that could be released from the soils in the aquatic environment.

The mild acid extraction technique is not the only method which can be used for assessing the "availability" of contaminants associated with particulate material, nor is it likely the best technique for assessing availability. Nevertheless, the mild acid extractable data are the only data that were provided which can be used to assess the question of availability. An understanding of the chemistry of mild acid extractions is essential to proper interpretation of the data.

Extraction techniques used to determine the amount of potentially available materials in a soil sample are based primarily on research conducted in the soil fertility field (Black, 1965; Jackson, 1970). Lee and Plumb (1974) have reviewed some of the extraction techniques presently used to assess availability. The extractants they site as being most frequently used include water, ammonium acetate, ammonium chloride, dilute hydrochloric acid, and dilute sodium hydroxide. According to Lee and Plumb (1974), ammonium chloride and ammonium acetate give an estimate of readily exchangable material. In these extractants, the ammonium ion replaced cations associated with the solids (usually by absorption). Dilute acid or dilute sodium hydroxide subjects sediments to harsher conditions and thus generally gives a higher result. The dilute extractable procedure probably measures not only readily exchangeable cations but also cations sorbed or trapped in acid soluble metal oxides and other materials (Lee and Plumb, 1974). Thus, the use of the acid extraction in this procedure is probably useful in terms of providing an upper estimate of the amount of material actually available in natural waters. In other words, the actual amount of available material is very likely less than that extracted by the dilute acid. This is true for both long term and short term "availability".

As Lee and Plumb (1974) also point out, the dilute acid extraction, as with all extraction procedures, must be interpreted in terms of volume of water available for dilution as well as the chemical environment that the element will be subjected to once it actually reaches the Great Lakes. For example, material initially soluble may be lost from solution in a period of time by sorption onto particulate material, or perhaps by other chemical processes. Lee and Plumb (1975), in a study of taconite tailings in Lake Superior, found that some heavy metals were initially leached from the tailings, but after a period of time they were lost from solution. This loss was attributed to sorption onto particulate material.

Table 13 shows a comparison of extractions by ammonium acetate and 0.05 N hydrochloric acid of calcium, magnesium, and sodium. These extractions were performed on selected soil samples collected from designated streambanks as part of the Task C effort of PLUARG as discussed previously. The data indicate that, in general, mild acid extractions provide higher results than the extractions with ammonium acetate. This is consistent with the premise that the acid extractable results provide a high estimate or an upper limit of the amount of "available" or exchangeable material. While the use of extraction procedures has been used rather successfully in the soil fertility field, there is still a great deal of uncertainty involved with operationaly defined extraction procedures to estimate the availability in the aquatic environment. In calcareous, alkaline soil, extracting with 0.05N HCl may be comparable to extracting with distilled water. This results when the alkalinity of the sample neutralizes the acid extracted. Thus, the results of the acid extractions depend to a certain extent on the soil type. Unfortunately, soil pH was not measured in the field and thus it is not possible to estimate the potential for neutralization of the acid extractant. However, based on the field descriptions of soil profiles when such information was available, few of the samples were determined to be highly alkaline.

TABLE 13 RESULTS OF IN NH_4-Ac AND 0.05N HCl EXTRACTION OF Ca, Mg AND Na FROM PLUARG STREAMBANK SOIL SAMPLES[1,2] (µg/g)

PLUARG Sample No.	Texture	Horizon	Ca NH_4Ac	Ca 0.05N HCl	Mg NH_4Ac	Mg 0.05N HCl	Na NH_4Ac	Na 0.05N HCl
1	sand	A	50	160	10	20	K25	K25
2		B	35	80	K5	25	K25	K25
4		A	1420	1760	255	325	K25	K25
5		B	650	710	190	220	K25	K25
6	silt	C	410	585	210	250	K25	K25
12		A	3870	6000	310	400	K25	K25
13		B	1200	2100	125	230	K25	K25
14	sand	C&II C	850	1860	95	210	K25	K25
15		A	3370	5600	440	605	K25	K25
18		A	3530	4560	570	660	50	45
19		B	2900	4370	570	795	60	65
20	silt	C	2020	2950	565	1000	50	50
21		A	6820	11300	708	995	45	35
22	clay	II&III C	6810	10500	520	745	60	75
30		A	4300	6000	185	335	K25	K25
31		B	2240	2610	190	340	K25	K25
32	sand	II C	1430	1910	140	285	30	K25
33		A	3320	5400	955	1950	40	K25
36		_	8810	33700	1590	9900	K25	45
41		A	6390	9150	1120	1670	K25	30
50		B	385	810	70	270	K25	K25

1 Analysis by U.S. EPA Central Regional Laboratory
2 K indicates less than

A number of other extractants, such as sodium hydroxide, citrate-dithionite-bicarbonate, ammonium oxalates, and anion exchange resins, are currently being used to assess availability of particulate material. It is helpful to examine these extractants and the techniques used in order to better interpret the 0.05 N HCl.

mean concentrations for the three different soil types (Table 8) as discussed earlier, calculations were made irrespective of the soil horizon of the sample.

The possibility of a relationship between samples taken from the face of the bluff or the top of the bluff with chemical concentration was also investigated. The sampling procedure used for the top and for the face of the bluff have been described previously. In general, there was found to be no relation between chemical concentrations and whether samples were taken from the face of the bluff or from the top of the bluff. Separate data for both the face and top of the bluff are available only for Michigan counties, so the number of samples available for comparison are somewhat limited. It is possible that samples taken from the exposed part of the face of the bluff could have different chemical characteristics compared to an unexposed sample taken from within the bluff. Exposure to the atmosphere and possible leaching by wave action could possibly change some of the chemical characteristics. However, there are no data available to show whether such differences occur. It is likely that any differences would be small and since the exposed surface of the shoreline would be small relative to the rest of the bluff, it is doubtful that any such differences would be quantitatively important in terms of chemical leaching to a lake. In fact, any chemicals that might be leached from the shoreline by wave action would probably enter the lake anyway.

TABLE 14 VARIATIONS OF TOTAL PHOSPHORUS WITH SOIL HORIZON OF SHORELINE SAMPLES

Horizon	Sandy Soils		Loamy Soils		Clayey Soils	
	$\overline{X}$	n	$\overline{X}$	n	$\overline{X}$	n
A	86	25	432	10	-	-
B	211	7	366	7	340	4
B[3]	60	4	-	-	-	-
C	89	48	366	15	413	9

$\overline{X}$ = mean concentration in µg/g
n = number of samples
1. Value excluding three B horizon samples from Oswego County that had high phosphorus concentrations

SHORELINE LOADING CALCULATION METHODOLOGY

BACKGROUND DATA

As part of subactivity 1-1(b), Armstrong et al.(1976)conducted a data search which consisted of a literature review and a mail survey of individuals and agencies likely to have shore erosion data of interest. Coastal researchers were requested to send published data and literature, copies of unpublished data, or information dealing with on going data collection efforts. Through this search all available information on bluff height, reach length, bluff recession and other shoreline data was obtained. The Armstrong et al. (1976) review was used as the primary data source for this study (Subactivity 1-2).

In addition to the report of Armstrong et al. (1976), the Great Lakes Basin Commission Framework Study Appendix 12, "Shore Use and Erosion" (Great Lakes Basin Commission, 1975), provided much background material for this report. Basic data on lake shoreline lengths, shore types, and other physical statistics were obtained from this work.

GENERAL METHODOLOGY

To calculate the volume of eroded material for any length of shoreline,information must be gathered on each of the three components that influence the volume of material entering the lake: bluffline recession rate, bluff height and shoreline length. Erosion rates can then be computed by multiplying the bluff line recession rate by the bluff height and the length of shoreline or reach length of interest. This approach, known as the rectangluar prism method for erosion rate derivations, was used in this report. Figure 2 shows how these three dimensions are combined to give the volumetric contribution to the lake.

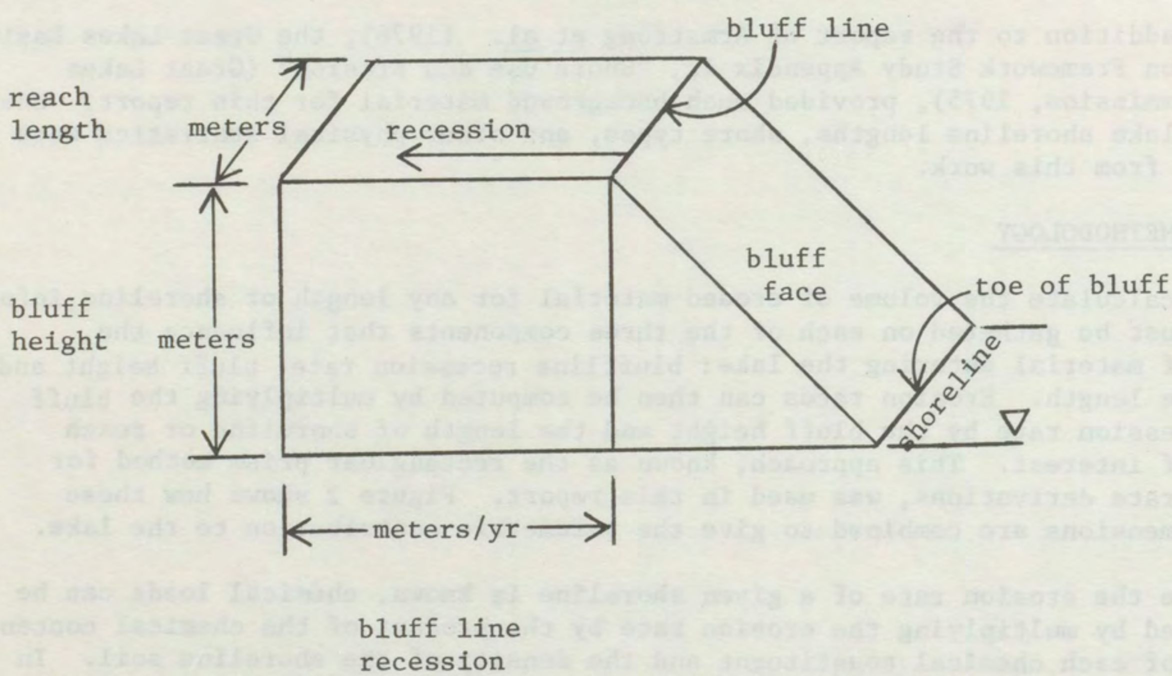
Once the erosion rate of a given shoreline is known, chemical loads can be calculated by multiplying the erosion rate by the product of the chemical concentration of each chemical constituent and the density of the shoreline soil. In this way the chemical loading in kilograms per year (or any convenient unit) can be obtained. The details of how these calculations were made are discussed below.

BLUFF HEIGHT

Bluff heights have not always been routinely measured by coastal zone researchers. The Task D Subactivity 1-1 (b) report by Armstrong et al. (1976) provides probably the first comprehensive listing of bluff heights for the U.S. Great Lakes shoreline. Armstrong et al. (1976) determined bluff heights from actual field measurement where available or from U.S. Geological Survey 7 1/2 minute or 15 minute quandrangle topographic maps. Bluff heights determined from topographic maps were felt to be accurate to plus or minus five feet. The Corps of

FIGURE 2

EROSION RATE DERIVATION
RECTANGULAR PRISM METHOD



Erosion = bluff height X reaches length X recession rate

$$\frac{m^3}{yr} = m \times m \times \frac{m}{yr}$$

Engineers shore type designations include information on bluff heights but only in terms of greater or less than 30 feet. Bluff heights reported by Armstrong et al. (1976) were used in this report.

Although bluff heights can change as erosion exposes new shoreline with a different topography, bluff heights measured from USGS maps are only accurate to plus or minus five feet and thus reasonable for the purposes of this project. Field measurements generally provide more accurate data and were used where available.

REACH LENGTH

The U.S. shoreline was divided up into 1,330 different sections or reaches. A new reach starts or ends in a given county whenever the shoretype changes or the average bluff height changes by more than five feet. By examining reaches individually, a rather detailed view of erosion trends in a given area can be obtained.

Armstrong et al. (1976) presented reach length data for those counties that had recession rate information available. These data were reported to the nearest tenth of a mile (the conversion to kilometers was also given). In this study the lengths of those reaches not covered in Armstrong et al. (1976) were measured in order that mileage for all U.S. shoreline reaches would be known. Measurements were made from U.S. Geological Survey 7 1/2 minute quad sheets where available or 15 minute quad sheets, using a standard mechanical map measure. Reach length measurements obtained in this way when summed give total shoreline distances that agree reasonably well with Corps of Engineer's shoreline distances given in Table 2 .

RECESSION RATE

Although bluff height and reach length are not time dependent and can be measured rather accurately, recession rate is a measurement of change over time and is more difficult to measure accurately. In particular, large year to year variations in recession rate can occur since recession depends on such factors as the frequency of storms, lake levels, topography, geological formation of the currently exposed bluff, vegetation and a variety of other factors. Reach length and bluff height can also conceivably change as erosion changes the length of bluff exposed to wave attack or exposes a bluff of new topography, however such changes are usually negligible compared to those encountered with recession rates. Recession rate is certainly the most difficult component to measure or estimate and is thus the most uncertain factor of the three components used to calculate erosion in this report.

Because of the short and long term variability of recession, an attempt has been made to view maximum and minimum recession rates as well as the average or mean rate likely to occur over a number of years. In this way shoreline erosion could be calculated for "average" recession conditions as well as for periods of high recession and low recession. Since it is currently not possible to know or predict recession with a high degree of accuracy, the ranges provided in this report should at least provide an indication of where the true value is likely to be found. In Subactivity 1-1 Armstrong _et al_. (1976) gathered all available recession data on the U.S. Great Lakes shoreline. They were able to compile maximum, minimum and average (a weighted average based upon the number of profiles measured for recession within a given reach) recession data to cover approximately 40 percent of the total U.S. erodible shoreline. Thus, a major task in this study (Subactivity 1-2) was to "estimate" recession rates for those reaches where no erosion rates are available. It should be mentioned at this point that although shoreline recession had to be "estimated" for about 60 percent of the erodible shoreline, most of the U.S. shoreline erosion occurs along the 40 percent of shoreline covered by recession "measurements". In general, "measured" recession rates tend to be found along those reaches where erosion is most severe.

In order to "estimate" recession rates for those reaches with no data, those reaches with available recession "measurements" as reported in Armstrong _et al_. (1976) were first tabulated. This tabulation was then examined to illuminate the gaps in the recession information. A maximum, minimum and average recession was then generated for reaches lacking recession data by extrapolating information from similar reaches as well as analyzing characteristics of the reach which may influence the rate at which it recedes.

Many factors must be considered when extrapolating recession information from one reach to another. The size and duration of storm induced waves has a direct influence on recession. These waves are dependent upon the velocity, direction, duration, and fetch of the wind. High lake levels aggravate the recession problem by allowing smaller storm waves to strike directly against the bluff. While it is possible that recession rates would lessen if lakes were lowered they would not be stopped. Another factor to consider is the physical makeup and location of the bluff. Sandy bluffs that are susceptable to direct wave attack will recede at a faster rate than a clay bluff that is in a protected bay. Other factors to consider are man made influences such as break waters, bottom topography, and the strength of the littoral current. Despite their importance no attempt was made to mathmatically account for these physical influences. However, these factors all were considered in a qualitative sense during the extrapolation process.

It is recognized that any extrapolation of recession information from one shoreline reach to another is judgemental and subject to considerable error. In order to provide a more reasonable "estimate", a range of values likely to occur was estimated for each erodible reach where possible. By providing a range of values, similar to that provided by Armstrong _et al_. (1976) in Subactivity 1-1(b), a better appreciation of the variability of recession rates can be obtained. The average or mean estimated recession rate was not meant to be the middle or medium value between the maximum and minimum, but was meant to reflect the average rate based on similiar reaches.

Available recession information for Lake Erie was generally limited to an average recession rate for each reach derived from the data of Carter (1975). From the information available on Lakes Superior, Michigan and Huron (Armstrong _et al_., 1976) it was observed that the maximum recession rate was generally about 80 percent greater than the average rate, and the minimum recession rate was generally about 60 percent less than the average rate. Assuming such a trend would hold for Lake Erie, a maximum and minimum recession rate for Lake Erie was calculated. The known average rate for each reach was multiplied by 1.8 to generate a maximum value and by 0.4 to generate a minimum recession rate.

Any reach length that was designated as nonerodible by the U.S. Army Corps of Engineers' National Shoreline Study was given a recession rate of zero. However, there were some reaches designed by the Corps of Engineers as nonerodible which had some "measureable" recession based on other studies. Whenever such a conflict arose, the actual data were used. Those areas that were designated as artificial fill areas by the Corps of Engineers were also considered as nonerodible.

Because of the lack of recession measurements for Lake Ontario shoreline, the estimation of recession rates along this lake necessitates a somewhat different procedure. Lake Ontario only had recession information available for Oswego County and those data were limited to average recession rates. To compute a total erosion load to Lake Ontario, the Oswego County recession data were extrapolated over the entire U.S. Lake Ontario shore. Oswego County has shoreline on both the south and east shore of Lake Ontario. The "measured" recession rates reported in Armstrong et al. (1976) varied from 0.25 m/yr to 0.37 m/yr for the southern shore and were 0.57 m/yr for the east shore. From these data as well as from information on shoreline composition, wind records and the wave trends, shore reaches in Niagra, Orleans, Monroe, and western portions of Wayne County were all assigned an average recession rate of 0.25 meters per year. The remaining portion of Wayne County and Cayuga County were assigned an average recession of 0.37 m/yr. The recession rate given to reaches in Jefferson County on the east shore varied from 0.57 m/yr to 0.0 m/yr depending on the location and shoreline composition. Maximum and minimum recession rates were also generated for the entire erodible U.S. Lake Ontario shore using the procedure developed for Lake Erie described earlier.

EROSION RATE

After the reaches in a given county were assigned recession rates or designated as nonerodible, erosion rates were computed. Each reach within a county was examined and a range of erosion rates was computed by multiplying the bluff height by the reach length and each of the three recession rate values (average, maximum and minimum). These three erosion rate values for each reach were added to erosion values in the other reaches in the county yielding the total volume eroded for that county. The counties were totaled to give the erosion in each planning subarea. Similarly, the planning subareas were totaled to give the erosion to each lake, and the lakes were totaled producing a final range of erosion rates likely to occur along the U.S. Great Lakes shoreline. The following formula was used to calculate erosion rates:

$$\underset{(\mathrm{m})}{\text{Bluff Height}} \quad \times \quad \underset{(\mathrm{m})}{\text{Reach Length}} \quad \times \quad \underset{(\mathrm{m/yr})}{\overset{\text{(Avg. Max. Min.)}}{\text{Recession Rate}}} = \underset{(\mathrm{m^3/yr})}{\overset{\text{(Avg. Max. Min.)}}{\text{Erosion Rate}}}$$

Armstrong et al. (1976) used this same procedure for each reach with available "measured" recession rates to calculate the erosion rates likely to occur per meter of reach. The calculations were made in English units giving erosion rates in cubic yards per year per foot of shoreline. This number was then converted into meters per year per meter of shoreline. In this report all calculations were made using metric units. Thus, when data on recession rate, bluff height or reach length were obtained from Armstrong et al. (1976) for an erosion calculation, the metric values were used and properly rounded to avoid conversion errors. The result of this methodoloy was to generate an average, maximum, and minimum erosion rate for every erodible reach along the U.S. Great Lakes Shoreline. A notation was made as to which of those reaches were based on actual "measurements" from the review of Armstrong et al. (1976) and which were derived from "extrapolated" recession information as derived in this study. The volume of material eroded was totaled for each county and a percentage of the volume eroded that was actually based on an "estimated" rather than "measured" values was computed. This same procedure was done on a planning subarea, lake basin, and Great Lakes Basin level.

Example of Erosion Calculation

Table 15 is an example of the reach by reach approach used in computing erosion rates for Charlevoix County, Michigan. This procedure was used in every county along the U.S. Great Lakes shoreline. Every U.S. shoreline reach was assigned a eight-digit number in Armstrong et al. (1976) indicating where the reach began and ended. The number corresponds to specific political boundaries. In this report this code was reduced to the county number and a letter corresponding to each reach. Figure 3 shows the location of Charlevoix County, Michigan, and the letters assigned to the reaches in the county. A list of county numbers for all Great Lakes counties can be found in the Introduction (Table 1). Each reach also has a particular shore type assigned by the U.S. Army Corps of Engineers. This information is provided in the second column of Table 15 . The length of the reach and the height of the bluff found in that reach are also given (in meters) in Table 15 .

In order to evaluate the validity of the final data, a record was kept on which reaches had recession rates that were based on actual "measurements" (either field measurements or areal photograph measurements) and which were based on "extrapolutions" from the "measured" data. This record is provided in the "Data Form" column (column five) of Table 15 . Recession rates compiled by Armstrong et al. (1976) in Subactivity 1-1 were derived from actual observations and were designated as such by the letter "M" for "measured" recession. Erodible reaches that have no "measured" recession data were assigned an "estimated" (or best guess) recession rate based on information available for similar reaches. These "estimated" or "extrapolated" values are identified by the letter "E" seen also in column five (Table 15). To provide a more descriptive evaluation of these "E" recession rate values a simple three letter code was developed that classified the estimates according to the amount the quality of information on which they were based. If an "estimate" was based on the recession rates found in a reach that had a similar configuration then that "estimate" was considered to have a Good or "G" information base. If the "estimated" recession rates were derived from a reach that had many but not all of the same characteristics the "estimate" was judged to have a Fair or "F" information base. Finally, if very little or no data existed for a reach similar to the one in question, the "estimate" was based on Poor or "P" information base. These codes are used only to describe "estimated" recession or erosion rates and are used on county, PSA, and Lake Basin totals as well. These codes are designed to provide the reader with a qualitative evaluation

TABLE 15

CHARLEVOIX COUNTY, MICHIGAN EROSION CALCULATIONS BY REACH

Reach Number	C.O.E. Shore Form	Reach Length[a] (Meters)	Ave. Bluff Height[a] (Meters)	Data Form[b]	Recession (m/yr) Ave.	Recession (m/yr) Max.	Recession (m/yr) Min.	Erosion (m^3/yr) Ave.	Erosion (m^3/yr) Max.	Erosion (m^3/yr) Min.	Soil Type
33A	PE	4020	5.33	M	0.12	0.49	acretion	2,571	10,499	0	Sand
33B	PE	6600	0.76	E F	0.1	0.5	0	502	2,508	0	Sand
33C	PE	2250	5.33	E F	0.1	0.5	0	1,199	5,996	0	Sand
33D	PN	3380	5.33	M	0.37	1.19	0.03	6,666	21,438	540	Sand
33E	PN	1770	0.76	-	0	0	0	0	0	0	
33F	PE	800	0.76	E F	0.1	0.5	0	61	304	0	Loam
33G	PE	4020	5.33	E F	0.1	0.5	0	2,143	10,713	0	Sand
33H	PE	800	0.76	E F	0.1	0.5	0	61	304	0	Sand
33I	PN	9500	0.76	-	0	0	0	0	0	0	
33J	LBN	3540	5.33	-	0	0	0	0	0	0	
Total Volume Measured (m^3/yr)								9,237	31,937	540	
Total Volume Estimated (m^3/yr)								3,966	19,825	0	
Soil Types											
Volume of Sand Eroded (m^3/yr)								13,142	51,458	540	
Volume of Loam Eroded (m^3/yr)								61	304	0	
Volume of Clay Eroded (m^3/yr)								0	0	0	
County Total (m^3/yr)								13,203	51,762	540	
Total Volume Eroded in County ($10^3 m^3$/yr)								13	52	1	

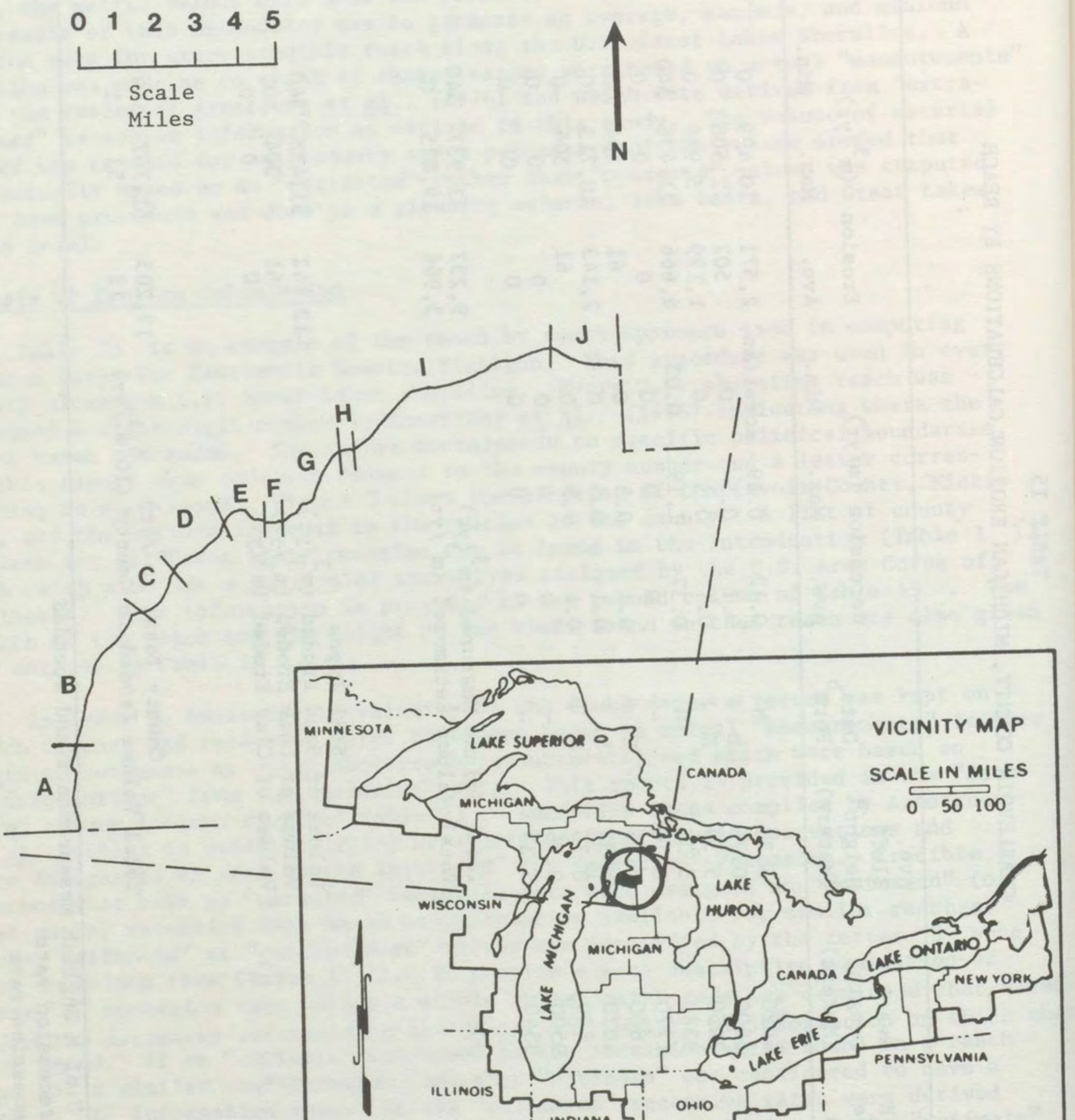
[a] derived from U of M English measurements and rounded

[b] E - estimated recession rate
M - measured recession rate
G - Good estimate
F - Fair estimate
P - Poor estimate

To Convert from	To	Multiply By
meters (m)	feet (ft)	3.281
cubic meters (m^3)	cubic feet (ft^3)	35.319

FIGURE 3

CHARLEVOIX COUNTY, MICHIGAN



of the reliability of the recession and erosion estimates that were made. They also are intended to illuminate those shoreline areas which might be considered for future recession measurements. Table 15 also indicates the average, maximum and minimum recession rates for each reach in the county (columns 6-8). Based on these recession rates, the bluff heights and the reach lengths, the computed erosion rates are given in Table 15 (columns 9-11). The last column in this table contains the predominate soil texture (sand, loam or clay) found in each reach. The importance of this information in terms of estimating chemical loadings will be discussed in a following section. Soil texture was determined based on available texture information where possible or from personal contact with individuals familiar with the area. Where no other information could be obtained, published county soil surveys were consulted and an estimate of whether the composition of the shoreline was predominantly sand, loam or clay was made. Information on the subsoils (rather than surface soils) given in the soil surveys was used whenever possible.

After the erosion rates had been calculated for each reach they were totalled under several categories. On Table 15 the "measured" volumes were totalled separate from the "estimated" values. This was done to distinguish the amount of erosion that was obtained based on actual "measurements" and the amount based on the "estimated" or "extrapolated" values. The volume of each of the three soil textures is also totalled separately for use in computing chemical loadings. Finally, a county total is presented and the total rounded off to the nearest thousand (m^3/yr). Both the unrounded and rounded numbers are presented to show the procedure used.

CHEMICAL LOADING

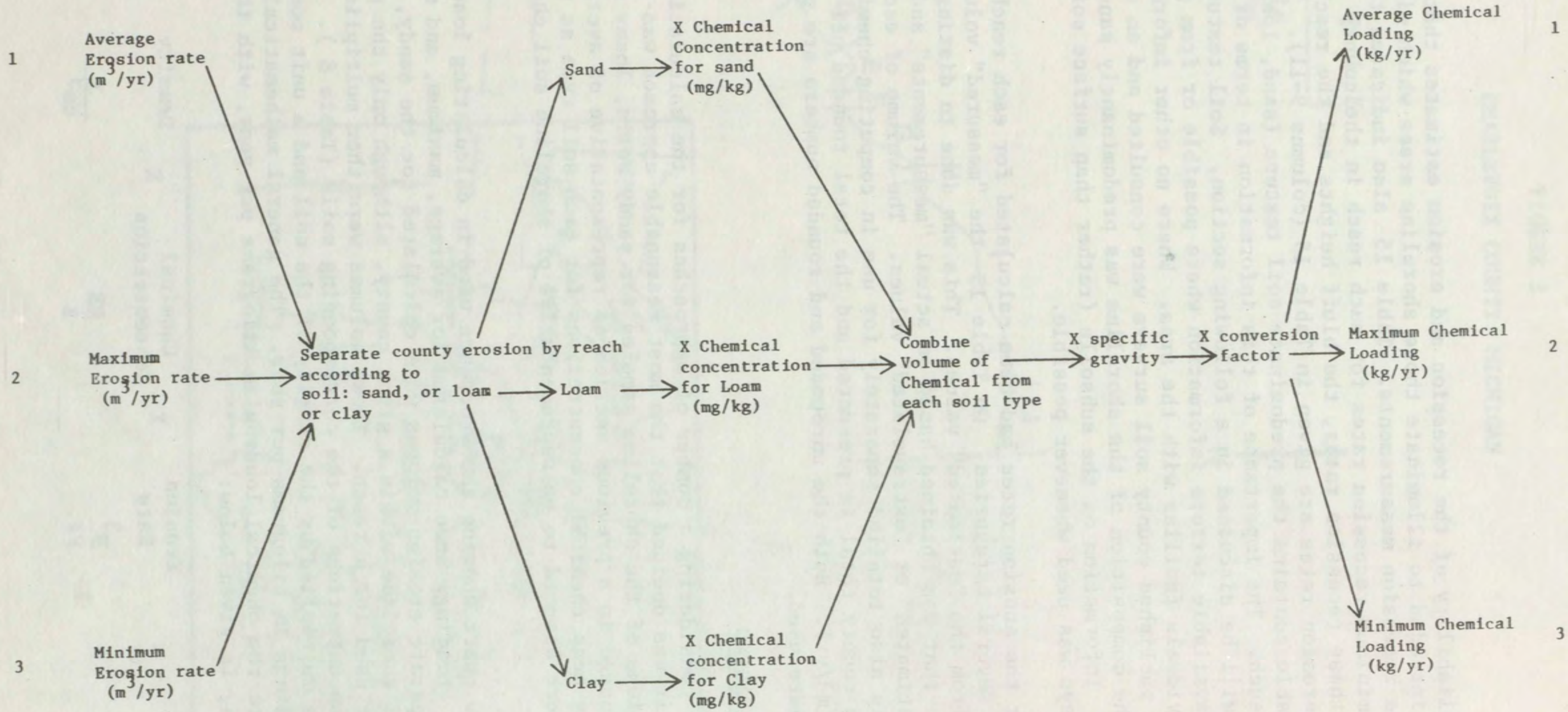
After considering a number of approaches for the calculation of chemical loadings, it was decided that the most reasonable approach was to use the mean concentrations of the shoreline samples for sandy soils, loamy soils, and clayey soils discussed in a previous section as representative of average soil conditions. In this way mean chemical concentrations for each soil type as presented in Table 8 were assumed to be representative of shoreline soil chemistry throughout the basin.

A flow chart showing the procedure used in calculating loadings is given in Figure 4 . Loadings were calculated for average, maximum, and minimum erosion rates. Separate erosion volumes were calculated for the sandy, loamy, and clayey sections of shoreline within a given county, although only the predominant soil texture was used for a reach. These volumes were then multiplied by the mean chemical concentrations of the corresponding soils (Table 8). The sum of this product was multiplied by the density of the soil and a unit conversion factor to obtain loadings in kilograms per year. The general mathematical expression used to calculate the chemical loading in kilograms per year, with the appropriate conversions, is given below:

$$\underset{\frac{kg}{yr}}{\text{Chemical Loading}} = \underset{\frac{m^3}{yr}}{\text{Erosion Rate}} \times \underset{\frac{\mu g}{g}}{\text{Chemical Concentration}} \times \underset{\frac{g}{cm^3}}{\text{Density}} \times \underset{\frac{10^6 cm^3}{m^3} \times \frac{kg}{10^9 \mu g}}{\text{Conversion Factor}}$$

FIGURE 4

CHEMICAL LOADING CALCULATION METHODOLOGY



The density of the soil was assumed to be equal to the measured specific gravity of the sample (i.e., the weight of soil per unit volume of water is assumed to be 1.0). A specific gravity of 2.6 was used for all calculations since, as previously discussed, this was the mean measured specific gravity and values varied relatively little from the mean.

Only total phosphorus, extractable total phosphorus, total Kjeldahl nitrogen, total magnesium, extractable magnesium, total iron, extractable iron, total manganese, extractable manganese, total aluminum, total calcium, and total lead loadings were calculated using this method. Loadings for other parameters were not calculated by this method due to lack of appropriate data or low concentrations in the soil samples that were analyzed. Table 16 shows the results of chemical loading calculations for Charlevoix County, Michigan. As was the case for erosion, this county is used to illustrate the method of the chemical loadings calculation process. Loadings were calculated for average, maximum and minimum erosion on a county basis. It should be realized that although results are presented to the nearest kg/yr, it is not implied that the numbers are significant at the kilogram level. Since county results were summed to provide PSA loadings, PSA loadings were summed to provide lake loadings and so on, the numbers in Table 16 have not been rounded in order to better show the procedure used.

County 33

TABLE 16

CHARLEVOIX COUNTY, MICHIGAN: CHEMICAL LOADING (kg/yr)

Chemical		Soil[a] Sand	Loam	Total	Chemical		Soil[a] Sand	Loam	Total
Total Phosphorus	Avg	3,401	63	3,464	Extractable Iron	Avg	2,721	30	2,750
	Max	16,901	316	17,217		Max	13,521	150	13,671
	Min	150	0	150		Min	120	0	120
Extractable Phosphorus	Avg	1,701	18	1,719	Total Manganese	Avg	3,741	70	3,811
	Max	8,450	92	8,542		Max	18,591	349	18,940
	Min	75	0	75		Min	164	0	164
Total Kjelduhl Nitrogen	Avg	5,782	153	5,935	Extractable Manganese	Avg	680	15	695
	Max	28,731	765	29,496		Max	3,380	75	3,455
	Min	254	0	254		Min	30	0	30
Total Magnesium	Avg	140,475	2,358	142,833	Total Aluminum	Avg	49,659	1,413	51,072
	Max	698,002	11,789	709,791		Max	246,751	7,064	253,815
	Min	6,174	0	6,174		Min	2,183	0	2,183
Extractable Magnesium	Avg	59,523	664	60,167	Total Calcium	Avg	286,731	4,426	291,157
	Max	295,764	3,320	299,084		Max	1,424,736	22,131	1,446,867
	Min	2,616	0	2,616		Min	12,603	0	12,603
Total Iron	Avg	187,413	2,896	190,307	Total Lead	Avg	170	5	175
	Max	931,233	14,468	945,701		Max	845	25	870
	Min	8,237	0	8,237		Min	7	0	7

To convert from	to		Multiply by
Kilograms (kg)	pounds (lb)	:	2.20246

[a] sand - reaches A-D, G, H
loam - reaches F,
Clay - no clay present

Reaches E, I, J are non-erodible

SHORELINE LOADING RESULTS

The information presented in this section consists of the physical and chemical shoreline loading values obtained for each county along the U.S. Great Lakes Shoreline. This information is summarized on a county, planning subarea, lake basin, and Great Lakes Basin level. These results were obtained from loading determinations done at the shoreline reach level as discussed previously. Shoreline loadings at the reach level are not reported here; however, this information is on file at the offices of the Great Lakes Basin Commission.

EROSION VOLUME

County and PSA

Table 17 provides erosion rate information for each county and planning subarea in the U.S. Great Lakes Basin. The county name and number have been provided starting with Lake Superior and following the shoreline through Lakes Michigan, Huron, Erie and finally Ontario. The county numbers, assigned by the Corps of Engineers in their National Shoreline Study, have been given previously.

Shoreline lengths in kilometers are also presented for each county and totalled for the planning subarea. As discussed previously, these shoreline lengths are only approximate, having been measured from 7 1/2 or 15 minute quad sheets. The next three columns on the table represent the average, maximum, and minimum erosion rates likely to occur for each county. These values are based upon the period over which recession measurements were made, which was generally about 35 years.

The Percent of Volume Estimated column in Table 17 is intended to provide an insight into the reliability of the given erosion volume from any county or PSA. For example, a two percent figure in this column would indicate that only two percent of the total volume for a given county was derived from "estimated" recession rates and the remaining 98% was obtained from "measured" recession. In this example the erosion volume should be considered very reliable. If on the other hand 75% of the total volume was derived from "estimated" data then the resulting erosion rates must be viewed critically.

To further aide in the interpretation of the results, another code, the realiability index, was used to describe the reliability of the estimated volume. This reliability index is meant to describe only the erosion rates calculated from "estimated" recession in this study (see previous section for explanation of method) and not the total erosion for any county or planning subarea. The "estimated" volume was obtained using Good, Fair, or Poor (G,F,P)

TABLE 17

VOLUME OF MATERIAL ERODED PER YEAR FROM COUNTIES AND PSA'S ALONG THE U.S. GREAT LAKES SHORELINE (Lake Superior)

County or PSA Number	Name	Shoreline Length (km)	Erosion (10^3 m^3/yr) Average	Maximum	Minimum	Percent of Volume Estimated[a]	Estimate Index[b]
1	Cook	159	0	0	0	0	G
2	Lake	96	0	0	0	0	G
3	St. Louis	35	33	49	8	100	F
4	Douglas	38	622	1,180	248	0	-
5	Bayfield	143	1,202	1,897	627	48	P
6	Ashland	54	178	287	92	100	P
7	Iron	6	183	271	90	100	P
PSA 1.1	Total	531	2,218	3,684	1,065	39	P
8	Gogebic	51	458	666	81	54	G
9	Ontonagon	91	65	115	33	1	G
10	Houghton	89	190	299	66	100	F
11	Keweenaw	147	204	372	87	59	G
12	Baraga	122	503	616	174	100	P
13	Marquette	120	201	410	89	93	P
14	Alger	137	180	315	58	100	F
15	Luce	52	125	237	38	47	G
16	Chippewa (Lk. Superior Portion)	145	194	329	68	76	F
PSA 1.2	Total	954	2,120	3,359	694	78	F

[a] The volume that was not estimated was derived from actual measurements

[b] Describes the validity of the Estimated volume of eroded material only. G-Good estimate, F-Fair estimate, P-Poor estimate.

TABLE 17 (continued)

VOLUME OF MATERIAL ERODED PER YEAR FROM COUNTIES AND PSA'S ALONG THE U.S. GREAT LAKES SHORELINE
(Lake Michigan)

County or PSA Number	Name	Shoreline Length (km)	Erosion (10^3 m^3/yr) Average	Maximum	Minimum	Percent of Volume Estimated	Estimate Index
35	Marinette	36	4	7	0	100	P
36	Oconto	46	3	10	0	100	P
37	Brown	58	4	13	0	100	P
38	Kewaunee	28	138	163	57	8	G
39	Door	230	18	52	5	100	P
40	Manitowoc	59	148	212	53	19	G
41	Sheboygan	44	76	99	58	31	G
PSA 2.1	Total	501	391	556	173	23	F
42	Ozaukee	45	590	705	519	10	G
43	Milwaukee	49	367	474	258	0	-
44	Racine	26	172	251	95	64	G
45	Kenosha	23	84	101	66	23	G
46	Lake Ill.	47	286	443	129	10	F
47	Cook	63	86	137	34	100	F
48	Lake Ind.	38	29	43	21	100	F
49	Porter	32	352	479	269	72	F
50	LaPorte	11	53	68	44	85	F
PSA 2.2	Total	334	2,019	2,701	1,435	31	F

TABLE 17 (continued)

VOLUME OF MATERIAL ERODED PER YEAR FROM COUNTIES AND PSA'S ALONG THE U.S. GREAT LAKES SHORELINE

(Lake Michigan)

County or PSA Number	Name	Shoreline Length (km)	Erosion (10^3 m^3/yr) Average	Maximum	Minimum	Percent of Volume Estimated	Estimate Index
21	Berrien	71	556	785	147	8	G
22	Van Buren	21	248	534	41	11	G
23	Allegan	41	827	1,317	427	1	G
24	Ottawa	43	481	1,036	80	0	-
PSA 2.3	Total	176	2,112	3,672	695	4	G
25	Muskegon	45	379	887	37	8	G
26	Oceana	44	337	808	37	0	-
27	Mason	49	346	955	1	0	-
28	Manistee	43	298	604	75	0	-
29	Benzie	43	363	827	20	6	G
30	Leelanau	164	1,441	3,163	304	29	P
31	Grand Traverse	123	209	364	2	91	P
32	Antrim	41	16	29	1	0	-
33	Charlevoix	37	13	52	1	30	F
34	Emmet	121	152	259	66	91	F
17	Mackinac (part of)	124	154	310	48	100	P
18	Schoolcraft	70	20	32	9	91	P
19	Delta	237	113	172	73	86	P
20	Menominee	69	13	23	5	58	P
PSA 2.4	Total	1,210	3,854	8,485	679	29	P

TABLE 17 (continued)

VOLUME OF MATERIAL ERODED PER YEAR FROM COUNTIES AND
PSA'S ALONG THE U.S. GREAT LAKES SHORELINE
(Lake Huron)

County or PSA Number	Name	Shoreline Length (km)	Erosion (10^3 m^3/yr) Average	Maximum	Minimum	Percent of Volume Estimated	Estimate Index
16	Chippewa (part)	151	18	37	K	66	P
17	Mackinac (part)	145	22	44	K	100	P
51	Cheboygan	58	33	67	0	80	F
52	Presque Isle	123	21	85	0	83	F
53	Alpena	106	16	43	0	100	P
54	Alcona	42	32	66	8	94	F
55	Iosco	57	57	85	34	58	G
56	Arenac	71	33	67	5	100	P
PSA 3.1	Total	753	232	494	47	82	F
57	Bay	76	15	30	1	100	P
58	Tuscola	32	6	12	0	100	P
59	Huron	119	48	116	8	100	P
60	Sanilac	63	195	358	113	20	G
61	St. Clair (part)	22	22	48	1	100	P
PSA 3.2	Total	312	286	564	123	46	P

K - less than 0.5 (10^3 m^3/yr)

TABLE 17 (continued)

VOLUME OF MATERIAL ERODED PER YEAR FROM COUNTIES AND PSA'S ALONG THE U.S. GREAT LAKES SHORELINE

(Lake Erie)

County or PSA Number	Name	Shoreline Length (km)	Erosion (10^3 m^3/yr) Average	Maximum	Minimum	Percent of Volume Estimated	Estimate Index
61	St. Clair (part)	79	26	51	0	100	P
62	Macomb	45	2	3	0	100	P
63	Wayne	72	1	2	0	100	P
64	Monroe	54	27	47	9	4	G
PSA 4.1	Total	250	56	103	9	53	P
65	Lucas	34	52	102	26	0	-
66	Ottawa	77[a]	54	112	8	1	G
67	Sandusky	15[a]	11	27	6	100	G
68	Erie (Ohio)	88[a]	77	143	34	46	G
PSA 4.2	Total	214[a]	194	384	74	24	G
69	Lorain	35	54	92	23	0	-
70	Cuyahoga	37	70	128	26	0	-
71	Lake (Ohio)	49	232	422	86	0	-
72	Ashtabula	43	148	270	55	0	-
PSA 4.3	Total	164	504	912	190	0	-
73	Erie (Penn)	66	602	1,095	223	0	-
74	Chautauqua	69	132	241	49	0	-
75	Erie (part)(N.Y.)	41	37	67	14	0	-
PSA 4.4	Total	176	771	1,403	286	0	-

[a] Includes portion of Sandusky Bay (57 km total)

TABLE 17 (continued)

VOLUME OF MATERIAL ERODED PER YEAR FROM COUNTIES AND PSA'S ALONG THE U.S. GREAT LAKES SHORELINE (Lake Ontario)

County or PSA Number	Name	Shoreline Length (km)	Erosion (10^3 m^3/yr) Average	Maximum	Minimum	Percent of Volume Estimated	Estimate Index
75[a]	Erie NY (part)	12	0	0	0	–	–
76[a]	Niagra	108	79	141	31	100	P
77	Orleans	40	16	30	7	100	P
78	Monroe	60	79	142	32	100	P
PSA 5.1	Total	220	174	313	70	100	P
79	Wayne	61	106	194	41	100	P
80	Cayuga	13	37	70	14	100	P
81	Oswego	56	131	233	47	0	–
PSA 5.2	Total	130	274	497	102	52	P
82[b]	Jefferson	283	103	185	40	100	P
83[b]	St. Lawrence	152	59	118	0	100	P
PSA 5.3	Total	435	162	303	40	100	P

To Convert from	To	Multiply by
kilometers (km)	miles (mi)	0.62114
cubic meters (m^3)	cubic feet (ft^3)	35.319

[a] Niagara River (63km total)
[b] Includes St. Lawrence River (243km total)

recession rate "estimates". The criteria for evaluating these "estimates" according to these three terms was strictly judgemental and has been previously discussed.

Lake Basin and Great Lakes Basin

Table 18 summarizes erosion calculations on individual lake basin and Great Lakes Basin level. Totals are derived from summing the PSA information and individual lake information, respectively. Shoreline length figures (in kilometers) do not agree exactly with the Corps of Engineers shoreline length figures given earlier in Table 2 . The reason for the differences, which are relatively small, is the different methods used for measuring shoreline length as discussed previously. The Corps of Engineers shoreline length values are mentioned only for comparison purposes and were not used in any calculations.

The percent of volume eroded and estimate index figures were based upon information obtained from the planning subareas within that lake. Rows four through seven on this table present the sediment load in metric tons per year. These values were obtained by multiplying the erosion rate values by a density of 2.6 g/cc.

CHEMICAL LOADINGS

County and PSA

Chemical loadings were computed for each of the U.S. Great Lakes shoreline counties and planning subareas for 12 different chemical parameters. An average, maximum and minimum chemical loading was computed in kilograms per year for each county and PSA as shown in Table 19 . All results in Table 19 have been rounded to the nearest 1000 kilograms.

The range of chemical loadings for each parameter is based solely on the range of erosion rates. No attempt was made to include possible ranges of density and chemical concentration for a particular soil type in these calculations. A complete discussion of the variability of the chemical and physical data obtained from analysis of shoreline samples (completed as part of Subactivity 1-1) may be found in a previous section of this report. It should be realized that chemical loadings derived in this study, although based on the best information available at this time, are only rough approximations.

Lake, Basin and Great Lakes Basin

Table 20 is a summary of the chemical loadings by lake and for the total U.S. Great Lakes Shoreline. These values were obtained by adding the chemical loading for the various planning subareas within the Lakes and the individual Lakes to give a Great Lakes Basin total. Average, maximum and minimum loadings are presented for 12 different parameters. The significance of these loadings will be discussed in detail in the following section.

TABLE 18

SEDIMENT LOAD FROM SHORELINE EROSION
U.S. GREAT LAKES

	U.S. Great Lakes Total	Lake Superior	Lake Michigan	Lake Huron	Lake Erie	Lake Ontario
Length of Shoreline[a] (kilometers)	6,360	1,485	2,221	1,065	804	785
Erosion Volume ($10^3 m^3$/year)						
Average	15,367	4,338	8,376	518	1,525	610
Maximum	27,430	7,043	15,414	1,058	2,802	1,113
Minimum	5,682	1,759	2,982	170	559	212
Erosion Weight[b] (10^3 metric tons/yr)						
Average	39,954	11,279	21,778	1,347	3,965	1,586
Maximum	71,318	18,312	40,076	2,751	7,285	2,894
Minimum	14,773	4,573	7,753	442	1,453	551
Percent of volume estimated	34	58	23	62	5	79
Estimate Index	F	F	F	F	G	P

To convert from	To	Multiply By meters to feet
kilometers (km)	miles (mi)	~~3.281~~ 0.62137
cubic meters (m^3)	cubic feet (ft^3)	35.319
metric tons	english short tons	1.102

[a] Includes 57 km of Sandusky Bay (L. Erie) and 243 km of St. Lawrence River (Lake Ontario)

[b] Assuming a density of 2.6 g/cc

TABLE 19

CHEMICAL LOADING FROM U.S. SHORELINE EROSION (10^3 kg/yr)

Lake Superior

County or PSA #	Name	Total Phosphorus Avg.	Max.	Min.	Extractable Phosphorus Avg.	Max.	Min.	Total Kjeldahl Nitrogen Avg.	Max.	Min.	Total Magnesium Avg.	Max.	Min.	Extractable Magnesium Avg.	Max.	Min.	Total Iron Avg.	Max.	Min.
1	Cook	0																	
2	Lake	0																	
3	St. Louis	8	13	2	4	6	1	14	22	4	351	526	88	149	223	37	468	702	117
4	Douglas	629	1,192	251	516	978	206	501	949	200	26,130	49,487	10,426	6,330	11,994	2,525	49,928	94,535	19,922
5	Bayfield	1,207	1,904	629	751	1,175	378	1,694	2,700	922	48,204	75,976	25,015	12,336	19,469	6,439	80,604	126,591	49,180
6	Ashland	165	266	86	134	216	69	136	219	71	6,840	11,048	3,554	1,696	2,738	882	12,945	20,913	6,724
7	Iron	185	275	92	152	226	75	147	219	73	7,699	11,422	3,807	1,864	2,766	922	14,713	21,828	7,276
Total PSA 1.1		2,194	3,650	1,060	1,557	2,601	724	2,492	4,190	1,270	89,224	148,459	42,890	22,375	37,190	10,805	158,658	264,569	83,219
8	Gogebic	452	658	80	131	190	23	1,095	1,592	194	16,862	24,526	2,990	4,748	6,906	842	20,693	30,099	3,670
9	Ontonagon	43	79	21	14	26	7	98	183	49	1,620	3,001	817	502	918	254	2,023	3,739	1,020
10	Houghton	155	247	62	47	75	18	368	586	148	5,842	9,288	2,299	1,713	2,717	654	7,220	11,475	2,827
11	Keweenaw	98	197	41	36	70	15	210	434	87	3,801	7,598	1,581	1,288	2,496	540	4,828	9,593	2,012
12	Baraga	497	609	172	144	176	50	1,202	1,475	416	18,520	22,712	6,414	5,215	6,395	1,806	22,728	27,873	7,871
13	Marquette	186	374	87	55	111	25	447	898	211	6,946	13,994	3,255	1,983	4,005	919	8,545	17,222	3,996
14	Alger	47	82	15	23	41	7	79	139	25	1,930	3,384	618	818	1,434	262	2,575	4,514	824
15	Luce	33	61	10	16	31	5	55	105	17	1,344	2,540	412	570	1,076	175	1,793	3,388	550
16	Chippewa (part)	76	130	21	34	59	11	142	244	34	3,020	5,169	850	1,081	1,846	333	4,087	6,995	1,187
Total PSA 1.2		1,587	2,437	509	500	779	161	3,696	5,656	1,181	59,885	92,212	19,236	17,918	27,793	5,785	74,492	114,898	23,957

K - Less than 0.5 (10^3 kg/yr)

TABLE 19 (continued)

CHEMICAL LOADING FROM U.S. SHORELINE EROSION (10^3 kg/yr)

Lake Superior

County or PSA #	Name	Extractable Iron Avg.	Extractable Iron Max.	Extractable Iron Min.	Total Manganese Avg.	Total Manganese Max.	Total Manganese Min.	Extractable Manganese Avg.	Extractable Manganese Max.	Extractable Manganese Min.	Total Aluminum Avg.	Total Aluminum Max.	Total Aluminum Min.	Total Calcium Avg.	Total Calcium Max.	Total Calcium Min.	Total Lead Avg.	Total Lead Max.	Total Lead Min.
1	Cook	0																	
2	Lake	0																	
3	St. Louis	7	10	2	9	14	2	2	3	K	124	186	31	716	1,074	179	K	1	K
4	Douglas	420	795	167	839	1,589	335	161	306	64	28,443	58,842	11,350	39,761	75,318	15,862	32	61	13
5	Bayfield	718	1,129	369	1,507	2,373	779	301	474	156	44,243	69,409	22,495	79,327	125,264	41,503	74	118	39
6	Ashland	111	179	57	218	353	113	42	68	22	7,286	11,775	3,784	10,521	16,988	5,467	8	14	4
7	Iron	124	183	61	247	367	122	48	71	24	8,384	12,438	4,146	11,713	17,377	5,792	10	14	5
Total	PSA 1.1	1,380	2,296	656	2,820	4,646	1,351	554	922	266	88,480	152,650	41,806	142,038	236,021	68,803	124	208	61
8	Gogebic	214	312	38	500	727	89	107	156	19	10,103	14,695	1,792	31,653	46,041	5,614	36	52	6
9	Ontongan	23	42	11	47	87	24	10	18	5	891	1,673	449	3,094	5,718	1,561	3	6	2
10	Houghton	78	173	30	172	273	68	36	58	15	3,383	5,389	1,366	11,044	17,552	4,324	12	19	5
11	Keweenaw	59	113	25	108	218	45	22	44	9	1,901	3,936	784	7,386	14,675	3,077	7	14	3
12	Baraga	235	289	81	549	673	190	118	144	41	11,096	13,608	3,843	34,766	42,634	12,039	39	48	14
13	Marquette	89	181	41	205	413	96	44	88	20	4,115	8,273	1,929	13,071	26,343	6,061	15	29	7
14	Alger	37	66	12	51	90	16	9	16	3	682	1,196	218	3,940	6,907	1,261	2	4	1
15	Luce	26	49	8	36	68	11	7	12	2	475	898	146	2,744	5,184	842	2	3	K
16	Chippewa (part)	51	87	16	85	146	23	17	28	4	1,533	2,633	392	5,847	9,998	1,671	5	8	1
Total	PSA 1.2	812	1,312	262	1,753	2,695	562	370	564	118	34,179	52,301	10,919	113,545	175,052	36,450	121	183	39

K - Less than 0.5 (10^3 kg/yr)

TABLE 19 (continued)

CHEMICAL LOADING FROM U.S. SHORELINE EROSION (10^3 kg/yr)

Lake Michigan

County or PSA #	Name	Total Phosphorus Avg.	Max.	Min.	Extractable Phosphorus Avg.	Max.	Min.	Total Kjeldahl Nitrogan Avg.	Max.	Min.	Total Magnesium Avg.	Max.	Min.	Extractable Magnesium Avg.	Max.	Min.	Total Iron Avg.	Max.	Min.
35	Marinette	4	7	0	1	2	0	9	18	0	137	274	0	39	77	0	168	337	0
36	Oconto	3	10	0	1	3	0	8	25	0	128	384	0	36	108	0	157	471	0
37	Brown	2	8	0	2	7	0	2	8	0	96	362	0	27	99	0	171	657	0
38	Kewaunee	136	161	56	39	47	16	329	390	136	5,066	6,008	2,093	1,427	1,692	589	6,217	7,373	2,569
39	Door	16	48	4	8	21	3	29	95	4	633	1,844	155	172	506	40	958	2,625	281
40	Manitowoc	100	139	37	32	46	12	229	318	86	3,780	5,284	1,402	1,162	1,635	427	4,712	6,596	1,745
41	Sheboygan	71	91	55	21	27	16	170	220	131	2,640	3,419	2,037	752	976	579	3,246	4,206	2,504
Total PSA 2.1		332	464	152	104	153	47	776	1,074	357	12,480	17,575	5,687	3,615	5,093	1,635	15,629	22,265	7,099
42	Ozaukee	583	697	513	169	202	148	1,411	1,687	1,241	21,731	25,985	19,116	6,119	7,317	5,383	26,669	31,890	23,459
43	Milwaukee	368	475	258	211	279	144	572	717	413	14,549	18,831	10,171	3,775	4,867	2,651	23,422	30,657	16,172
44	Racine	131	192	71	41	60	22	306	450	166	4,929	7,240	2,683	1,470	2,157	802	6,111	8,974	3,328
45	Kenosha	23	28	18	11	14	9	41	49	32	954	1,150	750	394	475	310	1,265	1,525	995
46	Lake (Ill.)	268	418	118	79	123	35	644	1,007	283	10,002	15,622	4,418	2,847	4,440	1,265	12,298	19,203	5,438
47	Cook	84	135	34	24	39	10	205	327	82	3,151	5,041	1,260	887	1,420	355	3,867	6,187	1,547
48	Lake (Ind.)	7	11	6	4	6	3	13	19	9	307	460	230	130	195	97	409	614	307
49	Porter	91	125	70	46	62	35	155	212	119	3,777	5,147	2,888	1,600	2,181	1,224	5,039	6,867	3,852
50	LaPorte	14	18	11	7	9	6	23	30	19	569	733	469	241	310	199	759	977	626
Total PSA 2.2		1,569	2,099	1,099	592	794	412	3,370	4,498	2,364	59,969	80,209	41,985	17,463	23,362	12,286	79,839	106,894	55,724
21	Berrien	145	204	38	72	102	19	246	347	65	5,972	8,431	1,573	2,530	3,572	667	7,967	11,248	2,099
22	Van Buren	64	139	11	32	69	5	110	236	18	2,661	5,733	440	1,128	2,429	187	3,550	7,648	588
23	Allegan	215	342	111	107	171	56	365	582	189	8,875	14,138	4,590	3,761	5,991	1,945	11,841	18,868	6,124
24	Ottawa	125	269	21	63	135	10	213	458	35	5,163	11,122	860	2,188	4,713	364	6,888	14,839	1,147
Total PSA 2.3		549	954	181	274	477	90	934	1,623	307	22,671	39,424	7,463	9,607	16,705	3,163	30,246	52,603	9,958
25	Muskegon	99	231	10	49	115	5	168	392	16	4,070	9,522	396	1,725	4,035	168	5,430	12,704	528
26	Oceana	165	401	10	60	146	5	356	869	16	6,389	15,530	393	2,151	5,206	167	8,106	19,685	524
27	Mason	90	248	K	45	124	K	153	422	K	3,720	10,257	10	1,576	4,346	4	4,963	13,685	14
28	Manistee	101	190	36	44	86	13	196	355	78	4,060	7,659	1,408	1,548	3,009	475	5,287	10,041	1,787
29	Benzie	95	215	5	47	108	3	161	366	9	3,903	8,884	212	1,654	3,765	90	5,207	11,853	283
30	Leelanau	445	1,105	91	202	472	42	826	2,154	165	18,001	44,082	3,679	7,120	16,648	1,476	23,634	57,285	4,846
31	Grand Traverse	58	102	1	30	54	1	94	164	1	2,386	4,217	47	975	1,711	15	3,296	5,867	78
32	Antrim	4	8	K	2	4	K	7	13	K	170	316	11	72	134	5	226	421	15
33	Charlevoix	3	17	K	2	9	K	6	29	K	143	710	6	60	299	3	190	946	8
34	Emmet	42	71	19	20	34	9	75	125	34	1,734	2,918	788	713	1,208	316	2,297	3,872	1,028
17	Mackinac (part)	40	81	13	20	40	6	68	137	21	1,652	3,327	519	700	1,410	220	2,204	4,439	692
18	Schoolcraft	5	8	2	3	4	1	9	14	4	215	339	92	91	143	39	287	452	122
19	Delta	111	169	72	32	49	21	270	410	174	4,155	6,319	2,675	1,170	1,779	753	5,099	7,755	3,283
20	Menominee	3	6	1	2	3	1	5	10	2	139	250	50	59	106	21	186	334	67
Total PSA 2.4		1,261	2,852	260	558	1,248	107	2,394	5,460	520	50,737	114,330	10,286	19,614	43,799	3,752	66,412	149,339	13,275

K - Less than 0.5 (10^3 kg/yr)

TABLE 19 (continued)

CHEMICAL LOADING FROM U.S. SHORELINE EROSION (10^3 kg/yr)

Lake Michigan

County or PSA	Extractable Iron			Total Manganese			Extractable Manganese			Total Aluminum			Total Calcium			Total Lead		
	Avg.	Max.	Min.	Avg.	Max.	Min.	Avg.	Max.	Min.	Avg.	Max.	Min.	Avg.	Max.	Min.	Avg.	Max.	Min.
35 Marinette	2	3	0	4	8	0	1	2	0	82	164	0	258	515	0	K	1	0
36 Oconto	2	5	0	4	11	0	1	2	0	77	230	0	240	721	0	K	1	0
37 Brown	2	6	0	3	11	0	6	2	0	89	349	0	156	582	0	K	K	0
38 Kewaunee	64	76	27	150	177	62	32	38	13	3,032	3,586	1,254	9,499	11,234	3,930	11	13	4
39 Door	9	26	2	19	56	5	4	12	1	500	1,347	153	1,099	3,284	246	1	3	K
40 Manitowoc	53	74	19	110	154	41	23	32	9	2,097	2,912	785	7,208	10,090	2,669	7	10	3
41 Sheboygan	34	44	26	78	101	60	17	22	13	1,567	2,026	1,212	4,965	6,433	3,830	6	7	4
Total PSA 2.1	166	234	74	368	518	168	84	110	36	7,444	10,614	3,404	23,425	32,859	10,675	25	35	11
42 Ozaukee	276	330	243	644	770	567	138	165	121	13,020	15,569	11,453	40,793	48,779	35,884	46	55	41
43 Milwaukee	212	276	147	451	585	315	91	117	64	12,704	16,688	8,737	24,414	31,421	17,171	24	30	17
44 Racine	66	98	36	144	212	79	30	45	17	2,810	4,134	1,526	9,347	13,726	5,090	10	15	5
45 Kenosha	18	22	14	26	31	20	5	52	4	355	428	278	1,936	2,333	1,522	1	1	1
46 Lake (Ill.)	129	200	57	296	462	131	63	99	29	5,940	9,289	2,612	18,812	29,374	8,318	21	33	9
47 Cook	40	64	16	93	149	37	20	32	8	1,888	3,021	755	5,915	9,464	2,366	7	11	3
48 Lake (Ind.)	6	9	4	8	12	6	1	2	1	108	162	81	626	939	469	K	1	K
49 Porter	73	100	56	101	137	77	18	25	14	1,335	1,819	1,021	7,710	10,505	5,894	5	6	3
50 La Porte	11	14	9	15	20	13	3	4	2	201	259	166	1,161	1,495	958	1	1	1
Total PSA 2.2	831	1,113	582	1,778	2,378	1,245	369	541	260	38,361	51,369	26,629	110,714	148,036	77,672	115	153	80
21 Berrien	116	163	30	159	225	42	29	41	8	2,111	2,980	556	12,189	17,209	3,211	7	10	2
22 Van Buren	52	111	9	71	153	12	13	28	2	941	2,027	156	5,432	11,701	899	3	7	1
23 Allegan	172	274	89	236	377	122	43	68	22	3,138	4,998	1,623	18,116	28,857	9,369	11	17	6
24 Ottawa	100	215	17	138	296	23	25	54	4	1,825	3,932	304	10,538	22,702	1,755	6	13	1
Total PSA 2.3	440	763	145	604	1,051	199	110	191	36	8,015	13,937	2,639	46,275	80,469	15,234	27	47	10
25 Muskegon	79	184	8	108	254	11	20	46	2	1,439	3,366	140	8,308	19,437	808	5	12	K
26 Oceana	98	236	8	182	443	10	37	90	2	3,221	7,864	139	12,399	30,114	802	11	28	K
27 Mason	72	199	K	99	273	K	18	50	K	1,315	3,626	4	7,594	20,937	21	5	12	K
28 Manistee	71	137	22	112	209	40	21	40	8	1,734	3,116	708	8,088	15,361	2,734	6	11	2
29 Benzie	76	172	4	104	237	6	19	43	1	1,380	3,141	75	7,967	18,134	433	5	11	K
30 Leelanau	323	759	67	490	1,217	100	93	235	19	7,241	19,093	1,445	36,157	87,637	7,414	25	66	5
31 Grand Traverse	46	80	1	65	115	1	12	21	K	987	1,798	37	4,768	8,391	81	3	5	K
32 Antrim	3	6	K	5	8	K	1	1	K	60	112	4	346	644	23	K	K	K
33 Charlevoix	3	14	K	4	19	K	1	3	K	51	254	2	291	1,447	13	K	1	
34 Emmet	33	55	14	47	78	21	9	14	4	650	1,081	300	3,514	5,924	1,573	2	4	1
17 Mackinac (part)	32	64	10	44	89	14	8	16	3	584	1,176	183	3,372	6,792	1,059	2	4	1
18 Schoolcraft	4	6	2	6	9	3	1	2	K	76	120	32	438	691	187	K	K	K
19 Delta	53	80	34	123	187	79	26	40	17	2,489	3,786	1,603	7,800	11,863	5,022	9	13	6
20 Menominee	3	5	1	4	7	1	1	1	K	49	88	18	284	511	102	K	K	K
Total PSA 2.4	896	1,997	171	1,393	3,145	286	267	602	56	21,276	48,621	4,690	101,326	227,883	20,272	73	167	15

K - Less Than 0.5 (10^3 kg/yr)

TABLE 19 (continued)

CHEMICAL LOADING FROM U.S. SHORELINE EROSION (10^3 kg/yr)

Lake Huron

County or PSA #	Name	Total Phosphorus Avg.	Max.	Min.	Extractable Phosphorus Avg.	Max.	Min.	Total Kjeldahl Nitrogen Avg.	Max.	Min.	Total Magnesium Avg.	Max.	Min.	Extractable Magnesium Avg.	Max.	Min.	Total Iron Avg.	Max.	Min.
16	Chippewa	13	27	K	4	9	K	31	63	K	506	1,018	5	152	306	2	628	1,264	6
17	Mackinac (part)	6	11	K	3	6	K	10	19	K	231	472	5	98	200	2	309	630	6
51	Cheboygan	9	17	0	4	9	0	15	25	0	360	719	0	152	305	0	480	959	0
52	Presque Isle	5	22	0	3	11	0	9	38	0	221	914	0	94	387	0	295	1,220	0
53	Alpena	7	20	0	3	8	0	15	43	0	281	791	0	96	270	0	358	1,007	0
54	Alcona	8	18	2	4	9	1	14	29	4	344	712	88	146	302	37	458	949	118
55	Iosco	15	22	9	7	11	4	25	37	15	617	909	361	262	385	153	824	1,213	482
56	Arenac	14	29	1	6	11	1	30	60	2	563	1,130	54	197	396	23	719	1,445	72
Total PSA 3.1		77	166	12	34	74	6	149	314	21	3,123	6,665	513	1,197	2,551	217	4,071	8,687	684
57	Bay	7	14	K	3	5	K	15	31	K	277	555	11	94	188	4	352	705	15
58	Tuscola	2	3	0	1	2	0	3	5	0	66	132	0	28	56	0	88	176	0
59	Huron	25	71	2	9	24	1	56	160	4	980	2,698	90	322	852	38	1,237	3,381	121
60	Sanilac	178	334	100	53	98	30	427	803	239	6,655	12,471	3,745	1,907	3,554	1,080	8,192	15,337	4,615
61	St. Clair	6	12	K	3	6	K	10	21	1	231	514	15	98	218	6	309	686	20
Total PSA 3.2		218	434	102	69	135	31	511	1,020	244	8,209	16,370	3,861	2,449	4,868	1,128	10,178	20,285	4,771

K - Less than 0.5 (10^3 kg/yr)

TABLE 19 (continued)

CHEMICAL LOADING FROM U.S. SHORELINE EROSION (10^3 kg/yr)

Lake Huron

County or PSA	Extractable Iron			Total Manganese			Extractable Manganese			Total Aluminum			Total Calcium			Total Lead		
	Avg.	Max.	Min.	Avg.	Max.	Min.	Avg.	Max.	Min.	Avg.	Max.	Min.	Avg.	Max.	Min.	Avg.	Max.	Min.
16 Chippewa	7	14	K	15	30	K	3	6	K	287	576	2	961	1,933	9	1	2	K
17 Mackinac	4	9	K	6	13	K	1	2	K	82	167	1	472	964	10	K	1	K
51 Cheboygan	7	14	0	10	19	0	2	3	0	127	254	0	734	1,467	0	K	1	0
52 Presque Isle	4	18	0	6	24	0	1	4	0	78	323	0	451	1,866	0	K	1	0
53 Alpena	4	12	0	8	22	0	2	5	0	139	392	0	548	1,540	0	K	1	0
54 Alcona	7	14	2	9	19	2	2	3	K	121	252	31	701	1,453	180	K	1	K
55 Iosco	12	18	7	16	24	10	3	4	2	218	321	128	1,260	1,856	737	1	1	K
56 Arenac	9	18	1	16	32	1	3	6	K	270	542	19	1,101	2,211	110	1	2	K
Total PSA 3.1	54	117	10	86	183	13	17	33	2	1,322	2,827	181	6,228	13,290	1,046	3	10	K
57 Bay	4	9	K	8	16	K	2	3	K	139	277	4	539	1,078	23	K	1	K
58 Tuscola	1	3	0	2	4	0	K	1	0	23	47	0	135	270	0	K	1	0
59 Huron	15	39	2	28	78	3	6	16	K	506	1,457	32	1,893	5,172	184	2	5	K
60 Sanilac	86	160	49	197	369	110	42	79	24	3,930	7,399	2,200	12,530	23,460	7,059	14	26	8
61 St. Clair (part)	4	10	K	6	14	K	1	2	K	82	182	5	472	1,050	31	K	1	K
Total PSA 3.2	110	221	51	241	481	113	51	101	24	4,680	9,362	2,241	15,569	31,030	7,297	16	34	8

K - Less than 0.5 (10^3 kg/yr)

TABLE 19 (continued)

CHEMICAL LOADING FROM U.S. SHORELINE EROSION (10^3 kg/yr)

Lake Erie

County or PSA	Extractable Iron			Total Manganese			Extractable Manganese			Total Aluminum			Total Calcium			Total Lead		
	Avg.	Max.	Min.	Avg.	Max.	Min.	Avg.	Max.	Min.	Avg.	Max.	Min.	Avg.	Max.	Min.	Avg.	Max.	Min.
61 St. Clair (part)	11	22	0	22	45	0	5	9	0	530	1,060	0	1,330	2,660	0	1	3	0
62 Macomb	1	2	0	2	4	0	K	1	0	71	143	0	100	200	0	K	K	0
63 Wayne	1	1	0	1	2	0	K	K	0	39	79	0	55	110	0	K	K	0
64 Monroe	18	32	6	36	63	13	7	12	2	1,237	2,137	432	1,729	2,985	603	1	2	K
Total PSA 4.1	31	57	6	61	114	13	12	22	2	1,877	3,419	432	3,214	5,955	603	2	5	K
65 Lucas	35	69	17	70	138	35	14	26	7	2,382	4,664	1,175	3,328	6,516	1,642	3	5	1
66 Ottawa	31	64	5	66	138	11	13	28	2	1,868	3,829	310	3,556	7,485	558	3	7	1
67 Sandusky	7	18	4	14	36	8	3	7	1	482	1,217	264	674	1,701	369	1	1	K
68 Erie (Oh.)	40	75	18	89	167	40	18	35	8	2,164	4,104	1,019	5,206	9,713	2,307	5	10	2
Total PSA 4.2	113	226	44	239	479	94	48	96	18	6,896	13,814	2,768	12,764	25,415	4,876	12	23	4
69 Lorain	25	43	11	59	100	25	13	21	5	1,191	2,021	505	3,732	6,331	1,583	4	7	2
70 Cuyahogen	47	86	18	95	173	35	18	33	7	3,218	5,856	1,191	4,495	8,181	1,663	4	7	1
71 Lake (Oh.)	93	169	34	194	354	72	40	73	15	4,280	7,790	1,584	10,236	21,893	4,450	12	22	4
72 Ashtabuia	46	84	17	91	165	34	19	34	7	1,657	3,017	613	6,080	11,066	2,250	6	11	2
Total PSA 4.3	211	382	80	439	792	166	90	161	34	10,346	18,684	3,893	24,543	47,471	9,946	26	47	9
73 Erie (Penn.)	154	280	57	261	475	97	51	94	19	4,302	7,829	1,592	18,402	33,492	6,809	15	27	6
74 Chautauqua	62	112	23	145	263	53	31	56	11	2,922	5,319	1,081	9,156	16,663	3,388	10	19	4
75 Erie (NY)	17	32	6	40	74	15	9	16	3	817	1,487	302	2,560	4,660	947	3	5	1
Total PSA 4.4	233	424	86	446	812	165	91	166	33	8,041	14,635	2,975	30,118	54,815	11,144	28	51	11

K - Less than 0.5 (10^3 kg/yr)

TABLE 19 (continued)

CHEMICAL LOADING FROM U.S. SHORELINE EROSION (10^3 kg/yr)

Lake Erie

County or PSA #	Name	Total Phosphorus Avg.	Total Phosphorus Max.	Total Phosphorus Min.	Extractable Phosphorus Avg.	Extractable Phosphorus Max.	Extractable Phosphorus Min.	Total Kjeldahl Nitrogen Avg.	Total Kjeldahl Nitrogen Max.	Total Kjeldahl Nitrogen Min.	Total Magnesium Avg.	Total Magnesium Max.	Total Magnesium Min.	Extractable Magnesium Avg.	Extractable Magnesium Max.	Extractable Magnesium Min.	Total Iron Avg.	Total Iron Max.	Total Iron Min.
61	St. Clair (part)	19	38	0	9	18	0	36	72	0	742	1,485	0	214	427	0	1,072	2,144	0
62	Macomb	2	3	0	1	3	0	1	3	0	66	131	0	16	32	0	125	251	0
63	Wayne	1	2	0	1	1	0	1	1	0	36	72	0	9	18	0	69	138	0.
64	Monroe	27	47	10	22	39	8	22	38	8	1,136	1,962	396	275	475	96	2,171	3,750	758
Total PSA 4.1		49	90	10	33	61	8	60	114	8	1,980	3,650	396	514	952	96	3,437	6,283	758
65	Lucas	53	103	26	43	85	21	42	82	21	2,187	4,283	1,079	530	1,037	261	4,180	8,186	2,063
66	Ottawa	54	113	8	31	63	5	82	179	12	2,125	4,440	338	550	1,156	87	3,438	7,081	565
67	Sandusky	11	27	6	9	22	5	8	21	5	443	1,118	242	107	271	59	846	2,137	463
68	Erie (Oh.)	76	143	34	33	63	16	152	280	64	2,931	5,490	1,318	792	1,480	353	4,167	7,874	1,938
Total PSA 4.2		194	386	74	116	233	47	284	562	102	7,686	15,331	2,977	1,979	3,944	760	12,631	25,278	5,029
69	Lorain	53	90	23	15	26	7	129	219	55	1,988	3,373	843	560	950	237	2,440	4,139	1,035
70	Cuyahoga	71	130	26	58	106	22	57	103	21	2,955	5,378	1,093	715	1,302	265	5,647	10,277	2,089
71	Lake (Oh.)	170	310	63	69	125	25	351	639	130	6,552	11,925	2,424	1,924	3,501	574	8,931	16,255	3,305
72	Ashtabula	82	150	30	29	52	11	182	332	67	3,156	5,744	1,168	1,024	1,863	379	3,975	7,234	1,471
Total PSA 4.3		376	680	142	171	309	65	719	1,293	273	14,651	26,420	5,528	4,223	7,616	1,455	20,993	37,905	7,900
73	Erie (Penn.)	237	431	88	95	174	35	481	876	178	9,343	17,003	3,457	3,381	6,153	1,251	12,029	21,893	4,451
74	Chautaugan	131	238	48	38	69	14	317	576	117	4,877	8,877	1,805	1,373	2,500	508	5,986	10,894	2,215
75	Erie (NY)	37	67	14	11	19	4	89	161	33	1,364	2,482	505	384	699	142	1,674	3,046	619
Total PSA 4.4		405	736	150	144	262	53	887	1,613	328	15,584	28,362	5,767	5,138	9,352	1,901	19,689	35,833	7,285

K - Less than 0.5 (10^3 kg/yr)

TABLE 19 (continued)

CHEMICAL LOADING FROM U.S. SHORELINE EROSION (10^3 kg/yr)

Lake Ontario

County or PSA #	Name	Total Phosphorus Avg.	Max.	Min.	Extractable Phosphorus Avg.	Max.	Min.	Total Kjeldahl Nitrogen Avg.	Max.	Min.	Total Magnesium Avg.	Max.	Min.	Extractable Magnesium Avg.	Max.	Min.	Total Iron Avg.	Max.	Min.
75	Erie NY (part)	0																	
76	Niagra	78	140	31	22	40	9	188	338	75	2,895	5,212	1,158	815	1,467	326	3,553	6,396	1,421
77	Orleans	16	29	6	5	8	2	39	71	16	605	1,089	242	170	307	68	743	1,337	297
78	Monroe	78	141	31	23	41	9	189	341	76	2,914	5,245	1,166	820	1,477	328	3,576	6,437	1,430
Total PSA 5.1		172	310	68	50	89	20	416	750	167	6,414	11,546	2,566	1,805	3,251	722	7,872	14,170	3,148
79	Wayne	104	191	41	30	55	12	253	463	99	3,894	7,136	1,528	1,096	2,009	430	4,778	8,758	1,875
80	Cuyuga	37	69	14	11	20	4	88	167	33	1,362	2,577	515	384	726	145	1,672	3,163	633
81	Oswego	67	119	25	24	43	9	145	260	54	2,573	4,607	953	857	1,529	315	3,258	5,828	1,205
Total PSA 5.2		208	379	80	65	118	25	486	890	186	7,829	14,320	2,996	2,337	4,264	890	9,708	17,749	3,713
82	Jefferson	101	183	39	65	119	26	134	240	50	4,051	7,352	1,586	1,033	1,872	402	6,891	12,558	2,732
83	St. Lawrence	57	113	0	17	33	0	137	273	0	2,112	4,225	0	599	1,197	0	2,595	5,190	0
Total PSA 5.3		158	296	39	82	152	26	271	513	50	6,163	11,577	1,586	1,632	3,069	402	9,486	17,748	2,732

K - Less than 0.5 (10^3 kg/yr)

TABLE 19 (continued)

CHEMICAL LOADING FROM U.S. SHORELINE EROSION (10^3 kg/yr)

Lake Ontario

County or PSA	Extractable Iron Avg.	Extractable Iron Max.	Extractable Iron Min.	Total Manganese Avg.	Total Manganese Max.	Total Manganese Min.	Extractable Manganese Avg.	Extractable Manganese Max.	Extractable Manganese Min.	Total Aluminum Avg.	Total Aluminum Max.	Total Aluminum Min.	Total Calcium Avg.	Total Calcium Max.	Total Calcium Min.	Total Lead Avg.	Total Lead Max.	Total Lead Min.
75 Erie NY (Part)	0						18	33	7	1,735	3,123	694	5,435	9,783	2,174	6	11	2
76 Niagra	37	66	15	86	154	34	4	7	2	363	653	145	1,136	2,045	454	1	2	1
77 Orleans	8	14	3	18	32	7												
78 Monroe	37	67	15	86	155	35	19	33	7	1,746	3,143	698	5,470	9,846	2,188	6	11	2
Total PSA 5.1	82	147	33	190	341	76	41	73	16	3,844	6,919	1,537	12,041	21,674	4,816	13	24	5
79 Wayne	49	91	19	115	212	45	25	45	10	2,333	4,276	915	7,309	13,396	2,867	8	15	3
80 Cayuga	17	33	7	40	76	15	9	16	3	816	1,544	309	2,557	4,838	968	3	5	1
81 Oswego	34	69	14	73	132	27	15	27	6	1,315	2,359	491	4,983	8,916	1,843	5	8	2
Total PSA 5.2	105	193	40	228	420	87	49	88	19	4,494	8,179	1,715	14,849	27,150	5,678	16	28	6
82 Jefferson	61	111	24	127	231	50	25	46	10	3,796	6,925	1,510	6,610	11,970	2,570	6	11	2
83 St. Lawrence	12	25	0	17	34	0	3	6	0	224	448	0	1,295	2,589	0	1	2	0
Total PSA 5.3	73	136	24	144	265	50	28	52	10	4,020	7,373	1,510	7,905	14,559	2,570	7	13	2

To Convert from kilograms (kg)	To pounds (lb)	Multiply by 2.20246

K - Less than 0.5 (10^3 kg/yr)

TABLE 20

CHEMICAL LOADING FROM U.S. SHORELINE EROSION (10^3 kg/yr)

U.S. GREAT LAKES BASIN

Lake #	Lake Name	Total Phosphorus Avg.	Total Phosphorus Max.	Total Phosphorus Min.	Extractable Phosphorus Avg.	Extractable Phosphorus Max.	Extractable Phosphorus Min.	Total Kjeldahl Nitrogen Avg.	Total Kjeldahl Nitrogen Max.	Total Kjeldahl Nitrogen Min.	Total Magnesium Avg.	Total Magnesium Max.	Total Magnesium Min.
1	Superior	3,781	6,087	1,569	2,057	3,380	890	6,188	9,846	2,451	149,109	240,671	62,126
2	Michigan	3,711	6,369	1,692	1,528	2,672	656	7,474	12,655	3,548	145,857	251,538	65,421
3	Huron	295	600	114	103	209	37	660	1,334	265	11,332	23,035	4,374
4	Erie	1,024	1,892	376	464	865	173	1,950	3,582	711	39,901	73,763	14,668
5	Ontario	538	985	187	197	359	71	1,173	2,153	403	20,406	37,443	7,148
Total U.S. Shoreline		9,349	15,933	3,938	4,349	7,485	1,827	17,445	29,489	7,378	366,605	626,450	153,737

Lake #	Lake Name	Extractable Magnesium Avg.	Extractable Magnesium Max.	Extractable Magnesium Min.	Total Iron Avg.	Total Iron Max.	Total Iron Min.	Extractable Iron Avg.	Extractable Iron Max.	Extractable Iron Min.	Total Manganese Avg.	Total Manganese Max.	Total Manganese Min.
1	Superior	40,243	64,983	16,590	233,150	379,467	107,176	2,192	3,608	918	4,573	7,391	1,913
2	Michigan	50,299	88,959	20,836	192,126	331,101	86,056	2,333	4,107	972	4,143	7,092	1,897
3	Huron	3,646	7,419	1,345	14,249	28,972	5,455	164	338	61	327	664	126
4	Erie	11,854	21,814	4,212	56,750	105,299	20,972	588	1,089	216	1,185	2,197	438
5	Ontario	5,774	10,584	2,014	27,066	49,667	9,593	260	476	97	562	1,026	213
Total U.S. Shoreline		111,866	993,809	44,997	523,341	894,506	229,252	5,537	9,618	2,264	10,790	18,370	4,587

Lake #	Lake Name	Extractable Manganese Avg.	Extractable Manganese Max.	Extractable Manganese Min.	Total Aluminum Avg.	Total Aluminum Max.	Total Aluminum Min.	Total Calcium Avg.	Total Calcium Max.	Total Calcium Min.	Total Lead Avg.	Total Lead Max.	Total Lead Min.
1	Superior	924	1,486	384	122,659	204,951	52,725	255,583	411,073	105,253	245	391	100
2	Michigan	830	1,444	388	75,096	124,541	37,362	281,740	489,247	123,853	240	402	116
3	Huron	68	134	26	6,002	12,189	2,422	21,797	44,320	8,343	19	44	8
4	Erie	241	445	87	27,160	50,552	10,068	70,639	133,656	26,569	68	126	24
5	Ontario	118	213	45	12,358	22,471	4,762	34,795	63,383	13,064	36	65	13
Total U.S. Shoreline		2,181	3,722	930	243,275	414,704	107,339	664,554	1,144,679	277,082	608	1,028	261

To Convert from	To	Multiply by
kilograms (kg)	pounds (lb)	2.20246

DISCUSSION OF SHORELINE LOADINGS

ACCURACY OF ESTIMATES

Erosion rates were obtained on a reach by reach basis either from the Subactivity 1-1 work of Armstrong et al. (1976), in which erosion of a reach was derived from actual recession "measurements" (field measurements or aerial photo interpretation), or from "estimates" made in this study (Subactivity 1-2) for those reaches with no "measured" recession data. As discussed in detail previously, estimates made in this study were based on extrapolation of information from those reaches with reliable recession data available as reported in Armstrong et al. (1976). However, even "measured" recession data as reported in Armstrong et al. (1976) can be obtained from an extrapolation technique, such as when field recession information from one or more profiles within a reach is extrapolated over the whole reach. Thus, while both "measured" recession information and "estimated" information are subject to considerable error and are at best only first approximations, it is felt that erosion values based on actual "measurements" are inherently more reliable than extrapolation of information from one reach to another. It was determined that approximately 44 percent of the erodible U.S. shoreline had "measured" recession information available. This same portion of shoreline, however, contributed 66 percent of the total volume eroded from the U.S. shoreline. In other words, most shoreline erosion studies have centered on highly erodible areas. As a result, in spite of the overall low availability of "measured" recession rate information, only 34 percent of the total computed volumetric contribution from the U.S. Great Lakes shoreline is based on "estimated" recession rates.

Chemical loading data must also be considered as only a first approximation or order of magnitude estimate. Trying to predict chemical loading over the whole Great Lakes Basin from the analysis of only a few soil samples is impossible to do with any degree of accuracy. However, the attempt here has been to provide an order of magnitude estimate to determine whether shoreline erosion is a potentially significant source of pollution. It is important to realize that the chemical loadings given in this report should not be taken as absolute values. They can be compared with other sources of pollution to see if indeed shoreline erosion can be a significant land-derived source of pollution to the Great Lakes.

Improving the statistical reliability of loading measurements by greatly increasing the sampling program would require a tremendously expensive program. Thus, the method from which chemical loadings are estimated (from a few data points) is probably more statistically efficient at making a first order estimate of the significance of shoreline erosion. In fact, it probably would have been possible,and maybe just as logical to estimate chemical loading from known general chemical characteristics of soil obtained from the literature. However, the use of the EPA soil samples does enable comparison of actual shoreline data to the values found in the literature.

Every attempt has been made in this report to clearly show the procedures used in estimating both erosion and chemical loadings and to point out the assumptions made. For example, in presenting erosion volumes for different areas of the Great Lakes shoreline, an attempt was made to show the percent of the calculated value derived from "measured" recession data and the percent derived from "estimated" recession data. Similarly, an evaluation of the reliability of the "estimated" data was made. It is hoped that this report will stimulate a further refinement of the loadings from shoreline erosion as well as a refinement of the understanding of the effect of this erosion.

REGIONAL EVALUATION OF SHORELINE EROSION

The following discussion will present a description of the available data and an evaluation of its application. For the purposes of this report all nonerodible areas (as designated by the U.S. Army Corps of Engineers) were considered to have an erosion rate of zero. Also, for convenience in discussing the results, average erosion values will be primarily used.

Lake Superior

The western arm of Lake Superior (PSA 1.1) has a great deal of recession information available, particularly for the red clay area found in Douglas and Bayfield Counties. Not only do these counties contribute a heavy sediment load to the lake but because of the clayey soil they contribute a large chemical load. All of Douglas county and half of Bayfield have "measured" recession rate information available (See Table 17). Cook and Lake Counties are comprised of nonerodible material, as defined by the U.S. Army Corps of Engineers, and thus assumed to have an erosion rate of zero.

Although only 39 percent of the erosion input from planning subarea 1.1 was derived from reaches having "estimated" recession rates, those reaches are not similar to other reaches with existing information. As a result, the estimates are considered to be poor.

Planning Subarea 1.2 has very little "measured" recession information available. However, because of the uniformity in the soil type and the distribution of the available data, the estimates derived for those reaches lacking information were considered to be a fair representation of the actual situation. All the counties in this planning subarea contribute a fairly uniform amount of sediment to Lake Superior.

The total U.S. Lake Superior shoreline contributes an average of 4.3×10^6 cubic meters of material every year (Table 18). Of this value 58 percent was obtained by using "estimated" recession rates and these estimates were judged to be a fair representation of the actual situation.

Lake Michigan

In Planning Subarea 2.1 four of the seven counties have no recession rate information available at all. However, as can be seen in Table 17 , these four counties contributed only about 7 percent of the total volume eroded from PSA 2.1. The remaining 3 counties (Kewaunee, Manitowoc, and Sheboygan) contribute about 93 percent of the total volume of eroded material for the PSA. These 3 counties also have the majority of "measured" recession rate information.

Planning Subarea 2.2 contributes over 2×10^6 cubic meters of sediment each year to Lake Michigan. Of this volume, 31 percent was "estimated". Major data gaps include Cook County, Illinois, Lake County, Indiana, and LaPorte Co., Indiana. The "estimated" erosion rate is considered to be fair representation of the actual situation.

Planning Subarea 2.3 has one of the shortest shorelines in the U.S. Great Lakes Basin, however it contributes one of the largest sediment loads. This four county reach is very well documented with 96 percent of the eroded volume derived from "measured" recession rates. The "estimated" erosion for the remaining four percent was judged to yield a good approximation of actual conditions.

Planning Subarea 2.4 has the longest shoreline of any PSA in the U.S. Great Lakes Basin. The southern six counties (up to and including Leweenaw County) are very similiar to those found in PSA 2.3. A great deal of recession information exists for these counties. The northern portion of this planning subarea has scattered recession rate information. However, because of the low bluff heights, a much smaller volume of material is contributed by shoreline erosion from these counties. Of the volume eroding from this PSA, 71 percent was derived from "measured" recession rates. The remaining volume estimate was based on what was considered to be a poor information base.

Only 23 percent of the $8,376 \times 10^3$ cubic meters eroded each year into Lake Michigan was derived from "estimated" recession information. The overall reliability of the "estimated" recession rates and, therefore, erosion rates was considered to be only fair.

Lake Huron

Only 18 percent of the eroded material entering Lake Huron from PSA 3.1 (which includes the St. Marys River) was derived from "measured" recession rates. The remaining 82 percent of the volume was based on "estimated" recession. However, the reliability of the "estimated" erosion volume was considered to be fair. Over half of the volume computed for PSA 3.2 was derived from judged "measured" recession rates, but the "estimated" rates were judged overall to be poor since the reaches without data were not at all similar to reaches with data.

In summary, 62 percent of the 518,000 m^3 eroded from the U.S. Lake Huron shoreline was derived from "estimated" erosion information. The overall reliability of the "estimated" erosion volumes was considered to be fair.

Lake Erie

For the purposes of this report the Lake Erie Shoreline includes the St. Clair River, Lake St. Clair, and the Detroit River as well as a 57 kilometer portion of Sandusky Bay. Carter (1975) computed a total sediment load to Lake Erie from the U.S. shoreline. From his report covering recession along the Ohio, PA., and N.Y. sections of Lake Erie, an average recession and erosion rate was derived. This information was summarized in Armstrong et al. (1976). As was previously discussed the maximum and minimum erosion likely to occur along Lake Erie was mathematically generated from this average rate based on trends found for the other Lakes.

Carter (1975) only included a small portion of PSA 4.1 shoreline in his report. As a result 53 percent of the volumetric contribution of this PSA was derived from "estimated" erosion values. PSA 4.2 includes Sandusky Bay, Ohio. Because of studies on the Bay itself and the surrounding shoreline, the relatively small volume contributed by this PSA that was based on "estimated" recession rates is considered to have good reliability. All of PSA 4.3 is covered by "measured" recession information.

The sediment load value derived by Carter (1975) for PSA 4.4 appears to be low. When examining his estimated recession rates and considering the available bluff height information (Armstrong et al., 1976) in the area, his total volumetric input is less then would be expected. Of particular importance is Erie County, Pennsylvania, which has many high erodible bluffs above 20 meters in elevation. Carter (1976) describes the recession in this area as very slow (0 to 1ft/yr) to slow (1 to 3ft/yr). Even with these low rates large volumes are eroded (see Table 17).

Lake Erie has more information available on its erodible shoreline than any other Lake. Ninety five percent of the volumetric contribution to Lake Erie from shoreline erosion was derived from "measured" values. These measured values were based almost exclusively on the work of Carter (1975). Much of the 5 percent that was "estimated" came from the Michigan portion of Lake Erie and was considered to have good reliability.

Lake Ontario

Lake Ontario includes the Niagara River which is classified nonerodible. Oswego County is the only County on this Lake that has recession rate information available. Located in PSA 5.2, this recession information was extrapolated over the remaining U.S. shoreline of Lake Ontario and the St. Lawrence River to the New York - Canadian boundary. If it can be assumed that the Oswego County recession rates are representative of the entire Lake, then an erosion volume can be calculated. However, 79 percent of the eroded material determined in this way is based on "estimated" recession information. The erosion volumes derived by this procedure are considered to have poor reliability because of the lack of supporting information.

HIGH LOADING AREAS

Sediment loads from shoreline erosion vary widely over the U.S. Great Lakes shoreline. The controlling physical feature appears to be the height of the erodible bluff. An area can have a very high recession rate but if it has a low bluff it will contribute a relatively minor amount of material to the lake. On the otherhand, a section of shoreline that has a very high bluff and a low recession rate can contribute large amounts of material to the lake system.

Table 21 ranks the counties that contribute the largest amounts of material from the U.S. Great Lakes shoreline. These counties are all characterized by very high unstable bluffs. Figures 5 through 9 illustrate graphically how the volumetric contributions vary by county throughout the U.S. Great Lakes shoreline. The values indicated on these figures are total shoreline material loadings for each county. These figures were derived from Table 17 .

As can be seen in Figure 5 the most significant loads to Lake Superior are from Douglas, Bayfield, Gogebic, and Barga Counties and to a lesser extent Marquette and Keweenaw Counties which also have high loadings. Because of the prevalent high unstable bluffs occuring along the eastern shore of Lake Michigan, large volumes of material are also eroded from this area each year (See Figure 6). Relatively small amounts of material are eroded each year into Lake Huron from the U.S. shore. Sanilac County at the extreme south end of Lake Huron contributes the largest amount (Figure 7). Erie County, Pennsylvania and Lake County, Ohio, provide the most significant total load to Lake Erie (See Figure 8). Because of the unstable bluffs and prevailing wind in an easterly direction, the eastern shore of Lake Ontario is thought to be a major source of solids to the Lake (See Figure 9).

TABLE 21 SIGNIFICANT VOLUMETRIC CONTRIBUTION BY COUNTY

County	10^3 m^3/yr	Lake
Leelanau, Mich.	1,441	Michigan
Bayfield, Wis.	1,202	Superior
Allegan, Mich.	827	Michigan
Douglas, Wis.	622	Superior
Erie, Penn.	602	Erie
Ozaukee, Wis.	590	Michigan
Berrien, Mich.	556	Michigan
Baraga, Mich.	503	Superior
Ottawa, Mich.	481	Michigan
Gogebic, Mich.	458	Superior

Another way to examine erosion is as a rate of material input per kilometer of shoreline rather than as a total load per county. Table 22 ranks the most significant counties, the PSA's and the Lakes according to their erodibility per kilometer of shoreline. The shoreline considered is the total shoreline which includes the nonerodible as well as erodible shoreline. By examining this table a further understanding of the erodibility of various areas along the U.S.

FIGURE 5
TOTAL EROSION BY COUNTY

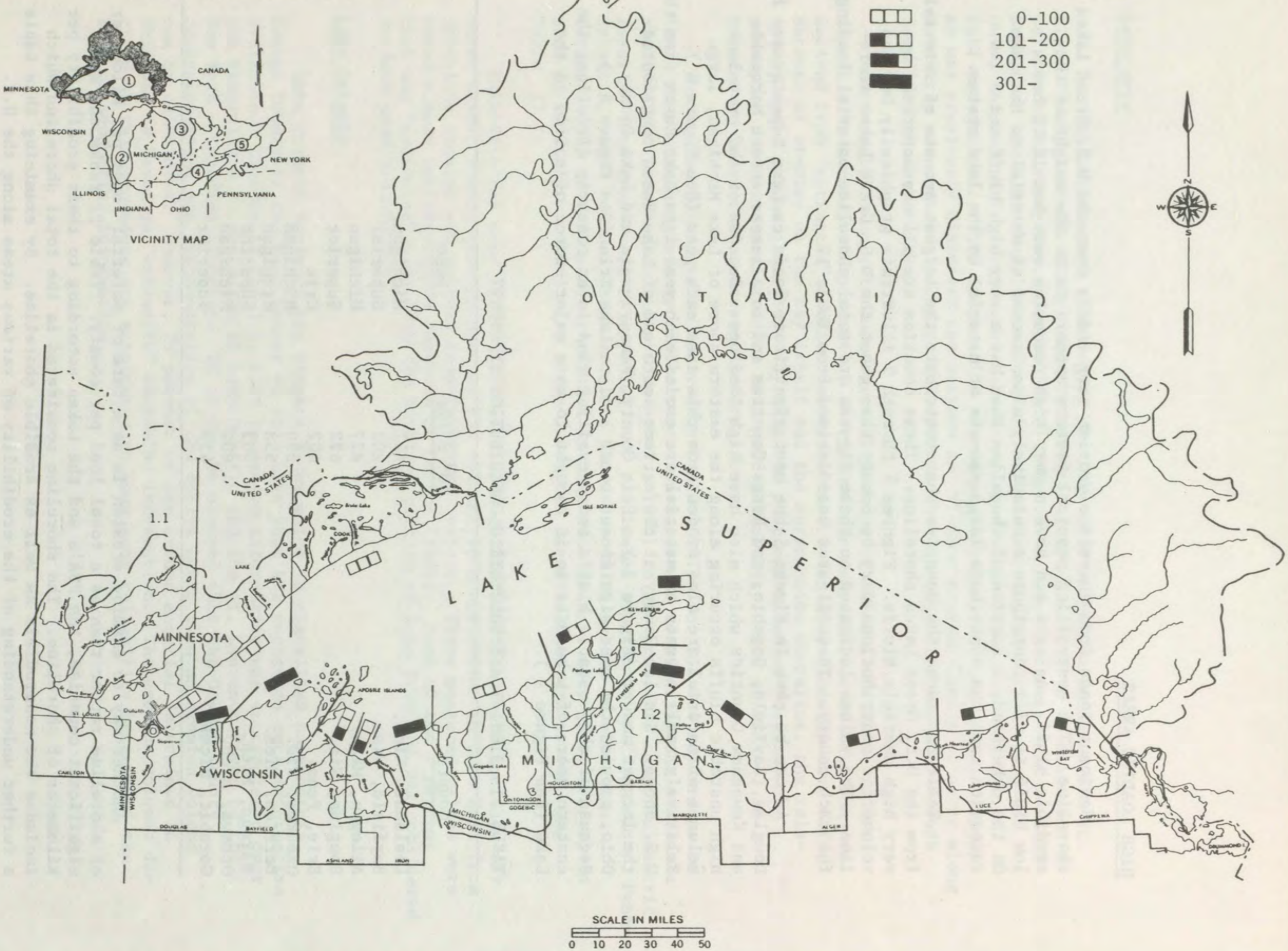


FIGURE 6
TOTAL EROSION BY COUNTY

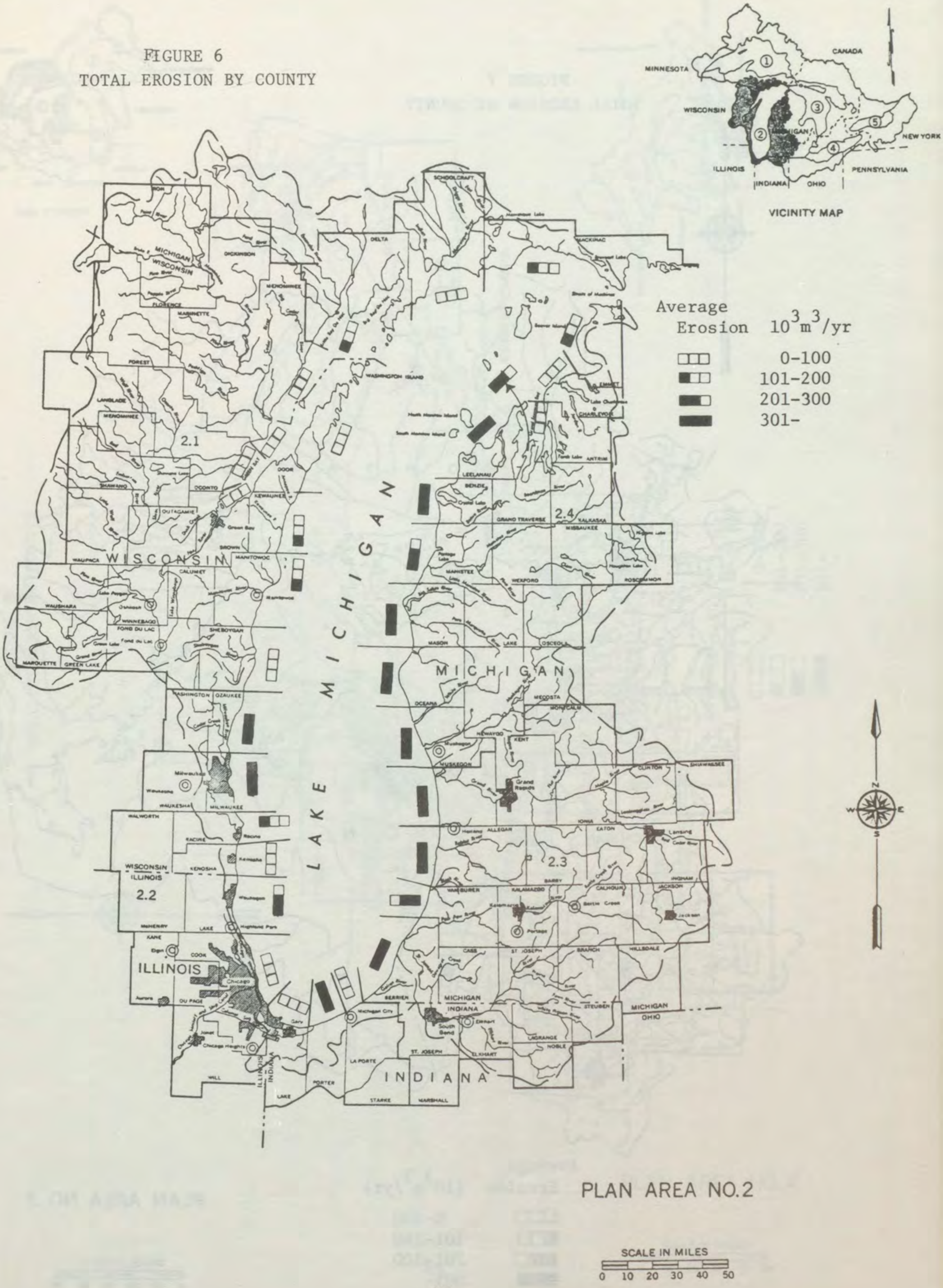
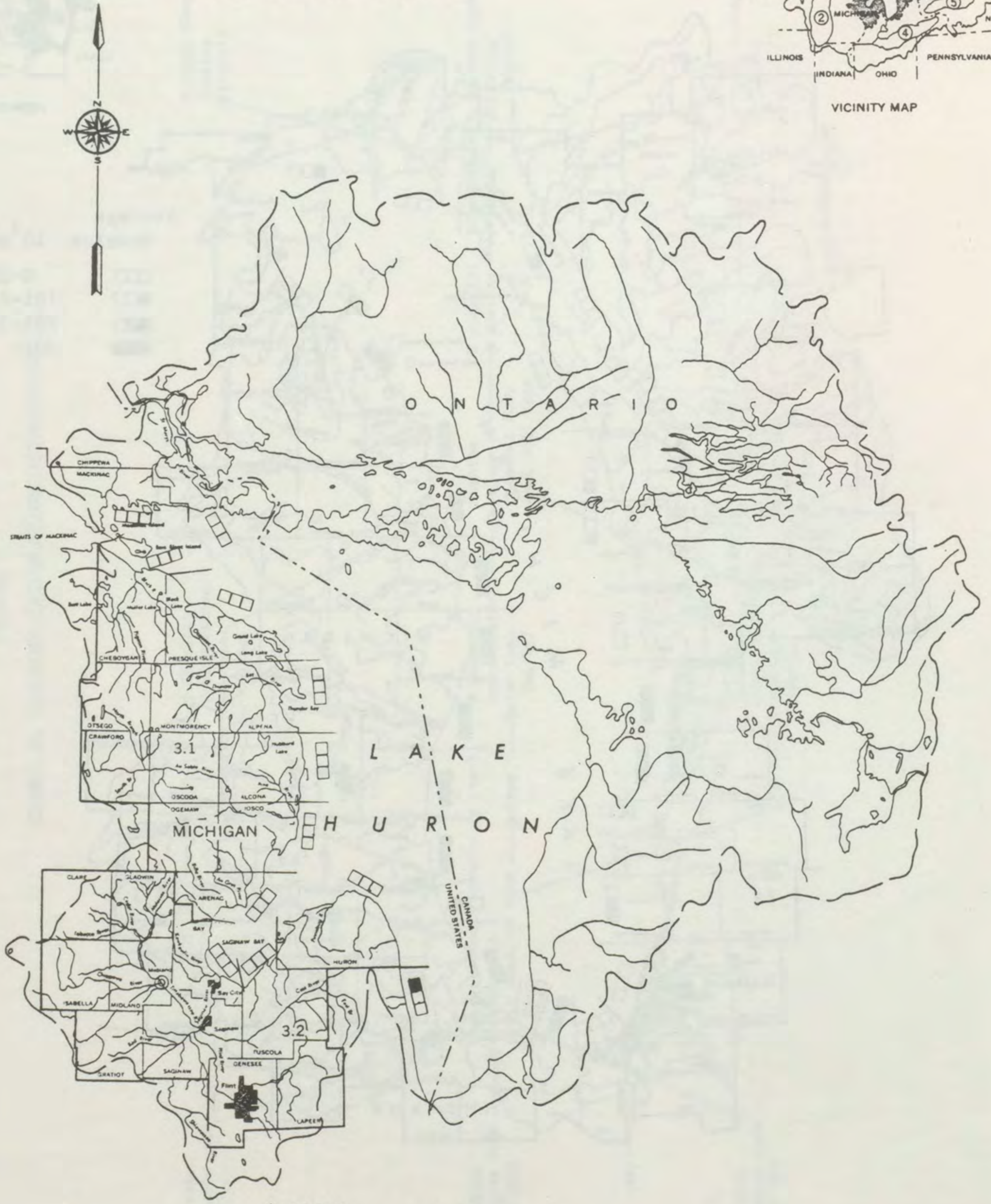


FIGURE 7
TOTAL EROSION BY COUNTY



Average
Erosion ($10^3 m^3$/yr)

	0-100
	101-200
	201-300
	301-

PLAN AREA NO. 3

SCALE IN MILES
0 10 20 30 40 50

FIGURE 8
TOTAL EROSION BY COUNTY

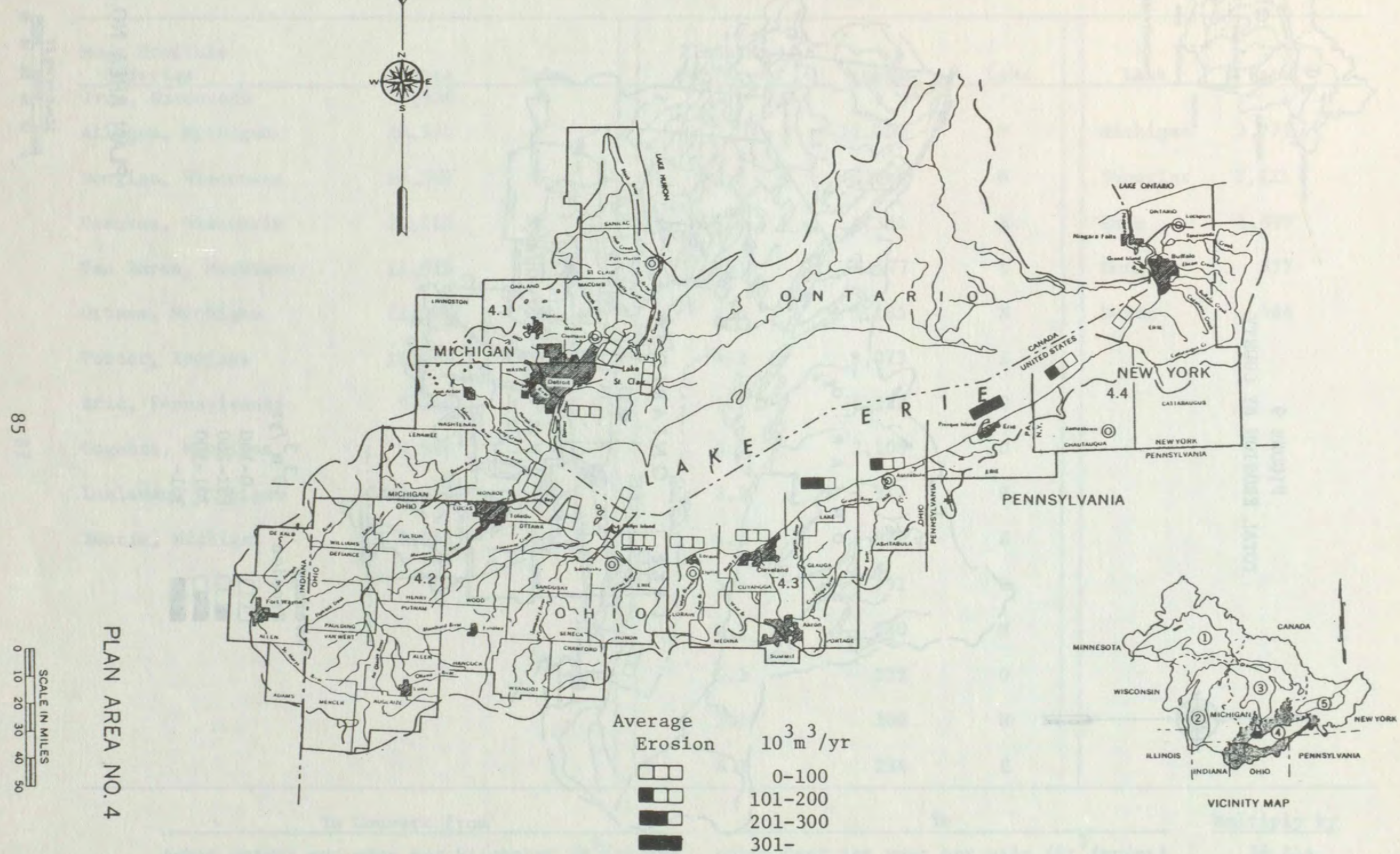


FIGURE 9
TOTAL EROSION BY COUNTY

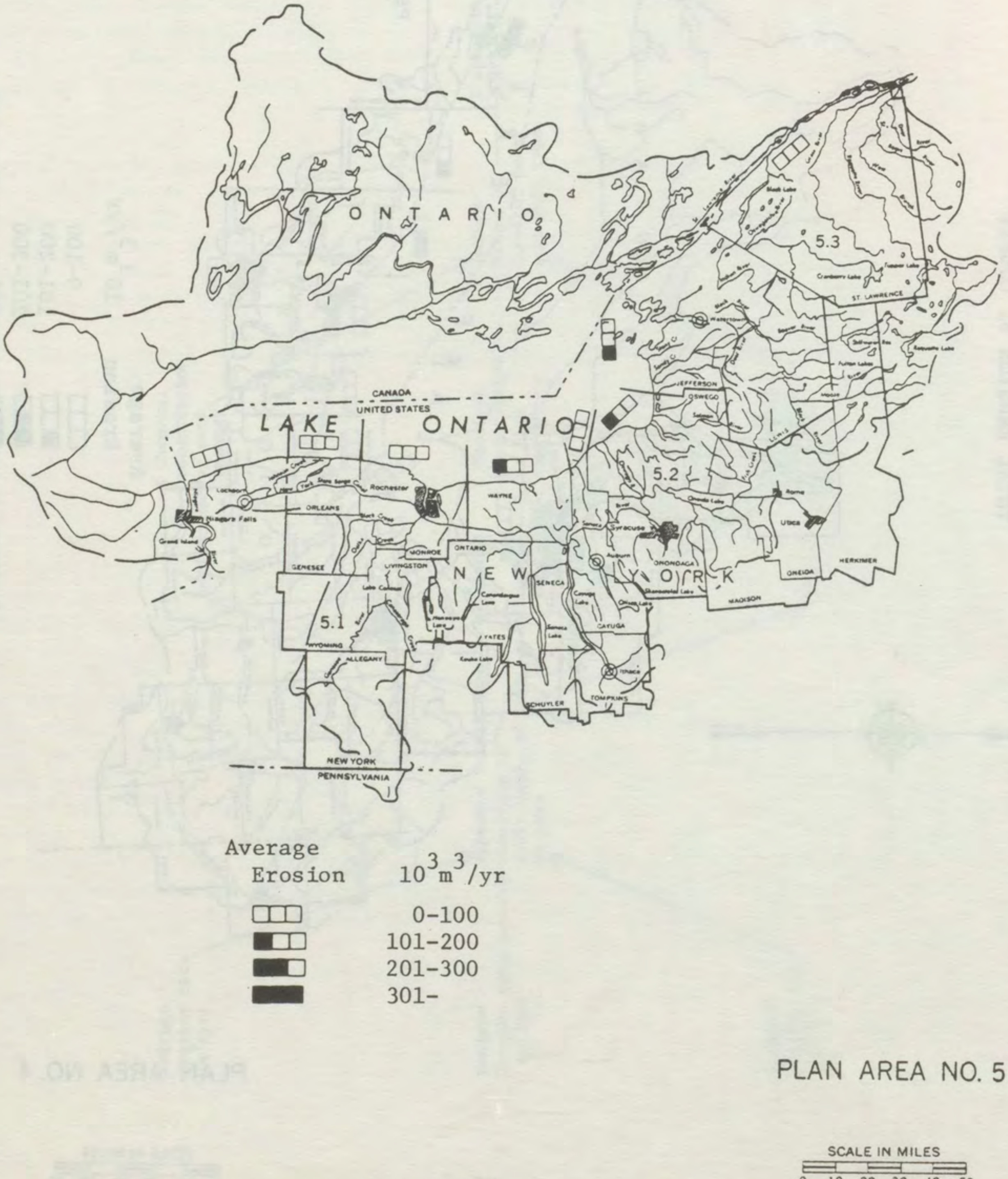


TABLE 22

AVERAGE EROSION PER KILOMETER OF U.S. SHORELINE[a] (m^3/yr/km)

Most Erodible Counties	Rate	Lake	Planning Sub Areas	Rate	Lake	Lake	Rate
Iron, Wisconsin	30,500	S					
Allegan, Michigan	20,171	M	2.3	12,000	M	Michigan	3,771
Douglas, Wisconsin	16,368	S	2.2	6,045	M	Superior	2,921
Ozaukee, Wisconsin	13,111	M	4.4	4,381	E	Erie	1,897
Van Buren, Michigan	11,810	M	1.1	4,177	S	Ontario	777
Ottawa, Michigan	11,186	M	2.4	3,185	M	Huron	486
Porter, Indiana	11,000	M	4.3	3,073	E		
Erie, Pennsylvania	9,121	E	1.2	2,222	S		
Gogebic, Michigan	8,980	S	5.2	2,108	O		
Leelanau, Michigan	8,787	M	3.2	917	H		
Benzie, Michigan	8,442	M	4.2	906	E		
			5.1	791	O		
			2.1	780	M		
			5.3	372	O		
			3.1	308	H		
			4.1	224	E		

To Convert from	To	Multiply by
cubic meters per year per kilometer (m^3/yr/km)	cubic feet per year per mile (ft^3/yr/mi)	56.814

[a] Includes all connecting rivers and non-erodible reaches

shoreline can be obtained. Table 22 shows that three of the ten most erodible counties are all located in PSA 2.3. In fact, the rate of erosion from PSA 2.3 is twice that of any other PSA. This erodibility Table reflects not only the recession rate within an area but the shore type, composition the bluff, bluff height and the amount of shoreline that is erodible.

SHORE EROSION COMPARED TO OTHER SEDIMENT SOURCES

There are many sources of sediment to the Great Lakes. Some of the more important sources are agricultural runoff, urban runoff, direct point source inputs from municipalities and industries, and shoreline erosion. A great deal of work has been done recently to determine the contribution to the Great Lakes from the different sources draining into the Great Lakes, as well as various point source discharges. One of the main objectives of this study was to determine the importance of shore erosion relative to other sources of pollutants to the Great Lakes.

Table 23 is a comparison of sediment loads from various sources. As can be seen from this table, shoreline erosion is a very significant source of sediment to the Great Lakes. Mildner (1974), in a report compiled for Task A of PLUARG, estimated average annual sediment yield from sheet and gully erosion from agricultural land for each lake in the U.S. Basin. He also compiled sediment loading data from urbanized areas in the Basin.

Mildner (1974) estimated that the combined urban and agricultural runoff from the U.S. portion of the Basin contributes about 4 million metric tons of sediment to the Great Lakes each year. Significantly, this number is about 10 times smaller than the approximately 40 million metric tons per year entering the Basin from U.S. shoreline erosion. The tributary loading of sediment for the entire U.S. Basin is 3.3 times smaller than shoreline erosion even considering the most conservative shoreline erosion estimate of about 15 million metric tons per year (as seen in Table 23). Since the shoreline is currently in a time of high recession and erosion rates, the current erosion situation is more likely closer to the maximum expected erosion load. The maximum loading, over 70 million metric tons per year, is over 16 times greater than the value attributed to tributaries by Mildner (1974). The following section will discuss the sediment load sources on a Lake basin level.

Lake Superior

In a report to the International Joint Commission on the status of the upper Lakes (Upper Lakes Reference Group, 1976), information on direct municipal, direct industrial, tributary, and atmospheric loadings to these two lakes from both the U.S. and Canadian side was presented. The most important sources of particulates to Lake Superior as given in this study are presented in Table 23 . As can be seen the shoreline erosion process, from the U.S. side only, contributes over 7 times as much sediment as the tributaries from both the Canadian and U.S. drainage areas to Lake Superior. The joint industrial inputs on the other hand are greater than those loadings from U.S. shoreline erosion, apparently as a result of the discharge of taconite tailings into Lake Superior by Reserve Mining Company.

TABLE 23

SEDIMENT LOADS TO THE GREAT LAKES (10^3 metric tons/year)

Source of Sediment		Great Lakes Total	Lake Superior	Lake Michigan	Lake Huron	Lake Erie	Lake Ontario
Tributaries[a] U.S. only 1973		4,316	56	1,310	224[e]	2,325[e]	403[e]
Tributaries[b] U.S. only 1975		–	–	–	–	4,000	–
Tributaries[c] U.S. & Canada 1973-1975		–	1,522	–	1,124[e]	–	–
Tributaries[d] U.S. & Canada 1975		–	–	–	–	6,460[e]	–
Direct Industries[c] U.S. & Canada 1973-1975		–	12,191	–	38	–	–
Shore Erosion U.S. only	Avg.	39,954	11,279	21,778	1,347	3,965	1,586
	Max.	71,318	18,312	40,076	2,751	7,285	2,894
	Min.	14,773	4,573	7,753	442	1,453	551

To Convert From	To	Multiply by
Metric Tons	English Short Tons	1.102

[a] Mildner, W.F. (1974)

[b] Carter, C.H. (1975)

[c] Upper Lakes Reference Group (1976)

[d] U.S. Army Corps of Engineers (1975)

[e] Does not include Load from Upstream Lake (i.e., St. Marys River or Detroit River, or Niagara River)

There is a considerable difference between the urban and agricultural input estimated by Mildner (1974) and the loadings from tributaries reported in Upper Lakes Reference Group (1976). Based on Mildner's (1974) values, the shoreline erosion would be about 200 times greater in terms of sediment load to the lakes than the sediment load from tributaries.

Lake Michigan

Information on total loading to Lake Michigan from tributaries is limited to the work of Mildner (1974). The particulates estimated to be contributed to the lakes from tributaries is almost 17 times less than the amount of material contributed by shoreline erosion.

Lake Huron

The sediment load from tributaries presented in the Upper Lakes Reference Group report is almost equal to the average erosion from the U.S. shoreline. However, this value for tributary loading includes the Lake Huron, Georgian Bay, and the North Channel for all of the U.S. and Canadian drainage area. The information available from the PLUARG Task A report (Mildner, 1974 U.S. side only) is approximately 6 times less then the average loading expected from shoreline erosion.

Lake Erie

The PLUARG Taks A report (Mildner, 1974) estimated that about 2 million metric tons per year are washed into Lake Erie from agricultural and urbanized areas from the U.S. side. This value, which does not include the Detroit River input, is almost 2 times smaller then the estimated average input from shoreline erosion. Information on tributary loadings to Lake Erie was also presented as part of the Lake Erie Wastewater Management Project (Corps of Engineers, 1975). They estimated that the total sediment load from tributaries on both the U.S. and Canadian side was over six million metric tons per year. When they include the load from the Detroit River the total solids input from rivers increases to nearly nine million metric tons per year. These values are 1.6 and 2.2 times greater, respectively, than the average estimated erosion load to Lake Erie. Carter (1975) estimated that the U.S. stream load was approximately four million metric tons per year. This is about equal to the average erosion load to Lake Erie from the U.S. shoreline as estimated in this study. If these tributary sediment loads are compared to the maximum expected U.S. shoreline erosion load (over seven million metric tons), they all are less then the shoreline erosion input.

Carter (1975) estimated that the total shore load into Lake Erie was approximately two million metric tons per year. This value coincides closely with the minimum value likely to occur as estimated in this report. As discussed previously, Carter's values appear to be somewhat low in the Pennsylvania and New York portions of the Lake Erie shoreline.

Lake Ontario

The sediment load from shoreline erosion into Lake Ontario from the U.S. side (approximately one and a half million metric tons per year) is almost 4 times greater then the tributary load compiled for the PLUARG Task A report (Mildner, 1974).

As can be seen from Table 23 tributary load estimates vary widely. This is to be expected considering the wide fluctuations in rainfall and other hydrologic occurances over any given period of study. Nonetheless, it is very clear that average shoreline erosion from the U.S. shoreline derived in this study is greater, and in some cases much greater, than the sediment load attributed to tributary runoff in the U.S. Basin.

POTENTIAL EFFECT OF PARTICULATE MATERIAL ON WATER QUALITY

Principal physical effects of particulate material eroded from the Great Lakes shoreline will be related to the problems associated with turbidity and sediment accumulation. Turbidity may cause reduced light penetration and subsequent interference with photosynthesis, interference with heat transfer, flocculation of algae, as well as a general deterioration of the aesthetic quality of the water. Accumulation of sediment on the bottom of the lake can bury benthic organisms and interfere with the growth of macrophytes. Effects of turbidity on water quality have been studied quite intensively and a number of review papers are available on the topic (May, 1973; Cairns, 1968; Hollis, et al., 1964; Cordone and Kelley, 1961).

Cairns (1968) has reviewed some of the mechanisms of sediment interaction. These include mechanical or abrasive action, blanketing action or sedimentation, reduction of light penetration, availability as a growth surface for bacteria and fungi, sorption and desorption of chemicals, and reduction of temperature fluctuations. As explained by Cairns (1968) the significance of these mechanisms are dependent upon a number of factors, such as concentration of the suspended solids, the presence of toxic materials associated with the suspended solids, the conditions and phase in the life cycle of the exposed organisms, and the type of solid suspended. Sorption or desorption of chemicals on or from suspended materials will be discussed in detail in a subsequent section.

Hollis et al. (1964) discussed that turbidity can cause a shift of species concentration from game fish to rough fish. The importance of this effect on Great Lakes fish composition is not known, but it would be interesting to determine if the high erosion rates in recent years had any effect on fish species composition. So many factors can effect species composition, some of which are random variables (e.g., random meteorological events), that it is extremely difficult to separate out specific effects of turbidity.

Perhaps the most obvious and economically important effect of turbidity is the water quality problems it can cause in connection with water supply intakes. High turbidity levels, caused at least in part from shoreline erosion, have created problems at a number of water intakes. The city of Cloquet, Minnesota, obtains its domestic water supply from Lake Superior. Water obtained from this intake has often been too turbid for domestic use. Sydor (1975) found that the water obtained through the Cloquet intake exceeded the drinking water standards for turbidity 53 percent of the time. Sydor concluded that this turbidity was primarily due to shore erosion as well as resuspension of bottom sediments.

Importantly, resuspension of bottom sediments, as well as shoreline erosion, can cause a considerable amount of turbidity in the Great Lakes. Currently, U.S. Task D of PLUARG is evaluating the effect of resuspension at a number of sites on the U.S. portion of the Great Lakes. Herdendorf (1976) in a study undertaken for U.S. Task D has found that a very large amount of turbidity occurs along the U.S. shore of western Lake Erie that is not derived from tributary input. The source of this turbidity appears to be a combination of shore erosion and resuspension of shallow water sediments. Currently, the relative importance of resuspension and shoreline erosion is not well known, although hopefully new information will be generated as part of U.S. Task D. To be sure, both shoreline erosion and resuspension of bottom sediments contribute heavily to the turbidity and suspended particulate material found in Great Lakes waters.

The Wisconsin shoreline of Lake Superior is subject extensive erosion of red clay, as discussed previously, and is responsible for much of the shoreline erosion loadings to Lake Superior. According to the Upper Lakes Reference Group (1976), the average open lake suspended solid concentration is approximately 0.7 mg/l, while waters in the western portion of the lake offshore of Duluth, the average suspended solid concentration is about 2.8 mg/l. During intense storms nearshore waters can have concentrations of up to 1,000 mg/l. Both shoreline erosion and resuspension can contribute to the increase.

Sydor (1975), in a study of red clay erosion and transport in Lake Superior, found that in the western basin during the open water season (May-November) 70 percent of the turbidity was contributed by shore erosion, 20 percent by resuspension and only ten percent by river runoff. During the winter months for times when the lake is ice free (December, January and April) Sydor estimated that resuspension contributed additional suspended material, about twice the amount contributed during the open water season. This would indicate that resuspension is very important, but that shore erosion contributes the majority of the annual suspended solids input to the western basin of Lake Superior.

Finally, the biological effect of suspended solids is hard to determine. As Lee and Plum (1974) have pointed out, it is difficult to determine the effect of suspended solids on benthic fauna and flora because very little is known about the response of organisms to increased rates of siltation. Some benthic species may tolerate or even thrive as a result of increased sedimentation. Tubificiae and Chironomids are examples of such organisms. However, because of the variability of populations, rate of sedimentation, responses of different species, movement of the sediment by currents, and many other interrelated factors, it is very difficult to explicitly define the effect of turbidity on benthic organisms.

SIGNIFICANCE OF LOST SHORELINE

Shoreline erosion is a natural process which has been going on for thousands of years. It must be recognized, however, that the eroded shoreline represents a lost natural resource to man not only for its aesthetic values but property and material value as well. It is also possible that the eroded material can have an important impact on the coastal waters and water quality of the entire Great Lakes system.

Table 18 indicates that the U.S. shoreline of Lake Erie is eroding at a rate of 1,525,000 m^3/yr. The entire volume of Lake Erie is approximately 5 x 10^{11} m^3. At this average erosion rate from the U.S. side only, it would take over 300,000 years to displace the volume of water now present in Lake Erie. The total average volume of material eroded each year from the U.S. Great Lakes shoreline is estimated at 15,184,000 m^3. This is equalivant to a cube with sides 248 meters (812 feet) long.

Because the rate at which any given shoreline reach will erode varies greatly from one year to the next, a range of values has been presented to reflect this occurrence. As discussed previously, an average, maximum and minimum value likely to occur in any given reach have been generated for the entire U.S. Great Lakes shoreline. The maximum value likely to occur for any lake varies between four and six times the minimum erosion rate expected and is about twice as great as the average erosion rate likely to occur. The range will of course vary widely from reach to reach but it does indicate the wide variation in volumes eroded from year to year in the various lakes.

POTENTIAL CHEMICAL IMPACT FROM SHORE EROSION

Because of the great volume of eroded soil from the bluffs along the Great Lakes, particularly in the last few years when lake levels have been high, it is not surprising that loadings of various chemical constituents from soil are high. It is most probable that a large percentage of the chemicals associated with the eroded shoreline material eventially becomes buried in the lake sediment. Once part of the historical sediment, it is unlikely that much interaction with the overlying waters occurs, at least for most of the chemical components. The sediments of the Great Lakes act as a natural sink of chemical toxicants, whether they are derived from shoreline erosion or elsewhere.

Material from shoreline erosion may actually increase the rate at which toxic and other chemicals are transported to the bottom by providing increased opportunity for sorption of chemicals onto particulate material. The uptake of trace materials, such as phosphorus or heavy metals, could be just as important environmentally as the release of contaminants from the shoreline materials.

Lee and Plumb (1974) and Lee *et al*. (1975) have discussed the uptake/release of contaminants associated with the disposal of dredged material. In many ways the effects of disposing dredged material into the Great Lakes are similar to the effects of shoreline erosion on the water quality. Although some dredged material may be potentially more harmful than shoreline material, the mechanisms which control the environmental consequence of adding dredge spoil to a lake are essentially the same as those operating on shoreline material eroded into a lake. Consequently, literature from the dredged material disposal field is useful in gaining an understanding of shoreline erosion effects on water quality.

The movement of contaminants into or out of sollution is not easy to predict and is a complex function of physical, chemical, and biological interactions. Factors affecting the uptake or release of materials from particulate materials such as pH, Eh and composition of the particulate material, have been reviewed by Lee (1970). Perhaps the most important factor in determining the importance of particulate material as a sink or a source of pollutants is the amount of dilution available. In general, this dilution would be high for particulates added by Great Lakes shorelines, particularly since those shores that erode rapidly are likely to have an open exposure to the main body of the lake. This would indicate that even if there were a significant release of contaminants from some of the Great Lakes shoreline material, its effect on the lake would be tempered by the tremendous dilution potential.

In addition to the redox potential and pH, the physio-chemical state of chemicals in the eroded soil can also affect the release of materials. As discussed previously, soils that contain large concentrations of hydrous oxides will tend to concentrate trace metals, phosphorus, and other contaminants.

Although sorption/desorption reactions are difficult to predict, one might expect that sorption reactions may be more important in Lake Erie while in Lake Superior dissolution reactions may be more common since solution chemical concentrations in Lake Erie are generally higher than the relatively pristine Lake Superior waters. For example, dissolved ortho phosphorus concentrations in Lake Erie tend to be on the order of 20 μg P/l, while those in Lake Superior are on the order of 4 μg P/l. Consequently, due to the different solution concentrations, there would be a greater tendency for phosphorus to be sorbed in Lake Erie waters compared to Lake Superior waters. However, other factors may affect exchange reactions between dissolved and particulate forms and, as Lee and Plumb (1974) point out, concentration gradients are often not effective in predicting transfer over the solid-water interface.

Phosphorus

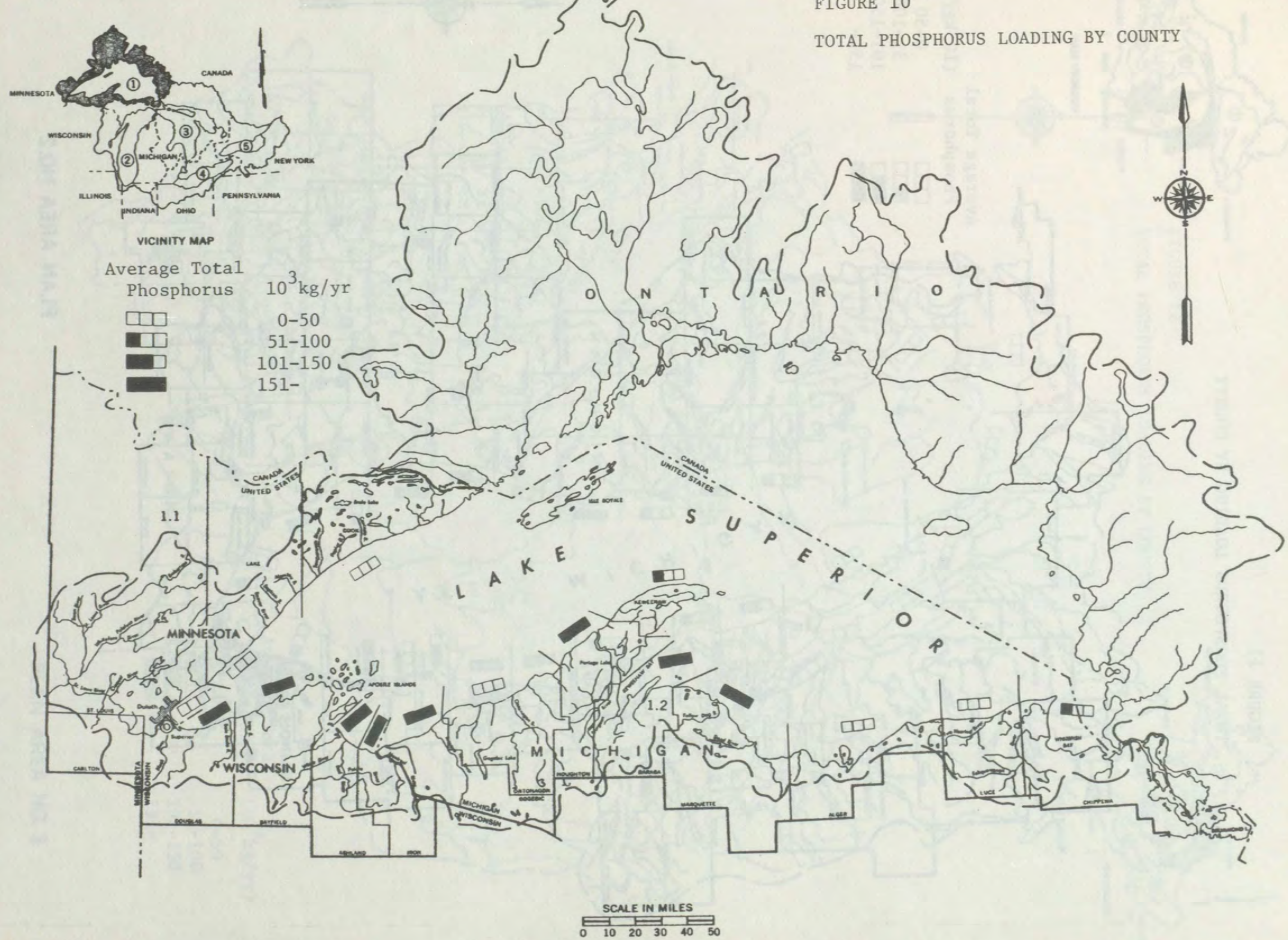
Geographic Distribution of Total Phosphorus Loadings from Shore Erosion.

Phosphorus is perhaps the most important nutrient component of shoreline erosion to consider, particularly in terms of the management strategies being developed to control phosphorus input to the Great Lakes. Figures 10 through 14 show the average inputs of total phosphorus from shore erosion from the various U.S. counties bordering the Great Lakes. In Figure 10, it can be seen that the total phosphorus loading is high for Douglas, Bayfield, Ashland, Iron, and Gogebic counties in the western end of Lake Superior. This is primarily due to the red clay erosion which occurs in this area. On the contrary, the rocky coastline along the north shore of Lake Superior produces very little total phosphorus from shoreline erosion. Some high loadings also occur from shorelines near the Keewanaw Peninsula. The shores of Houghton County, Baraga County, and Marquette County also appear to contribute large amounts of total phosphorus.

For Lake Michigan (Figure 11) the highest phosphorus loadings are located in the southern half of the lake. Ozaukee and Milwaukee counties in Wisconsin and Lake County in Illinois produce the highest total phosphorus loadings from shoreline erosion on the western side of Lake Michigan. On the eastern side of

FIGURE 10

TOTAL PHOSPHORUS LOADING BY COUNTY



PLAN AREA NO. I

FIGURE 11

TOTAL PHOSPHORUS LOADING BY COUNTY

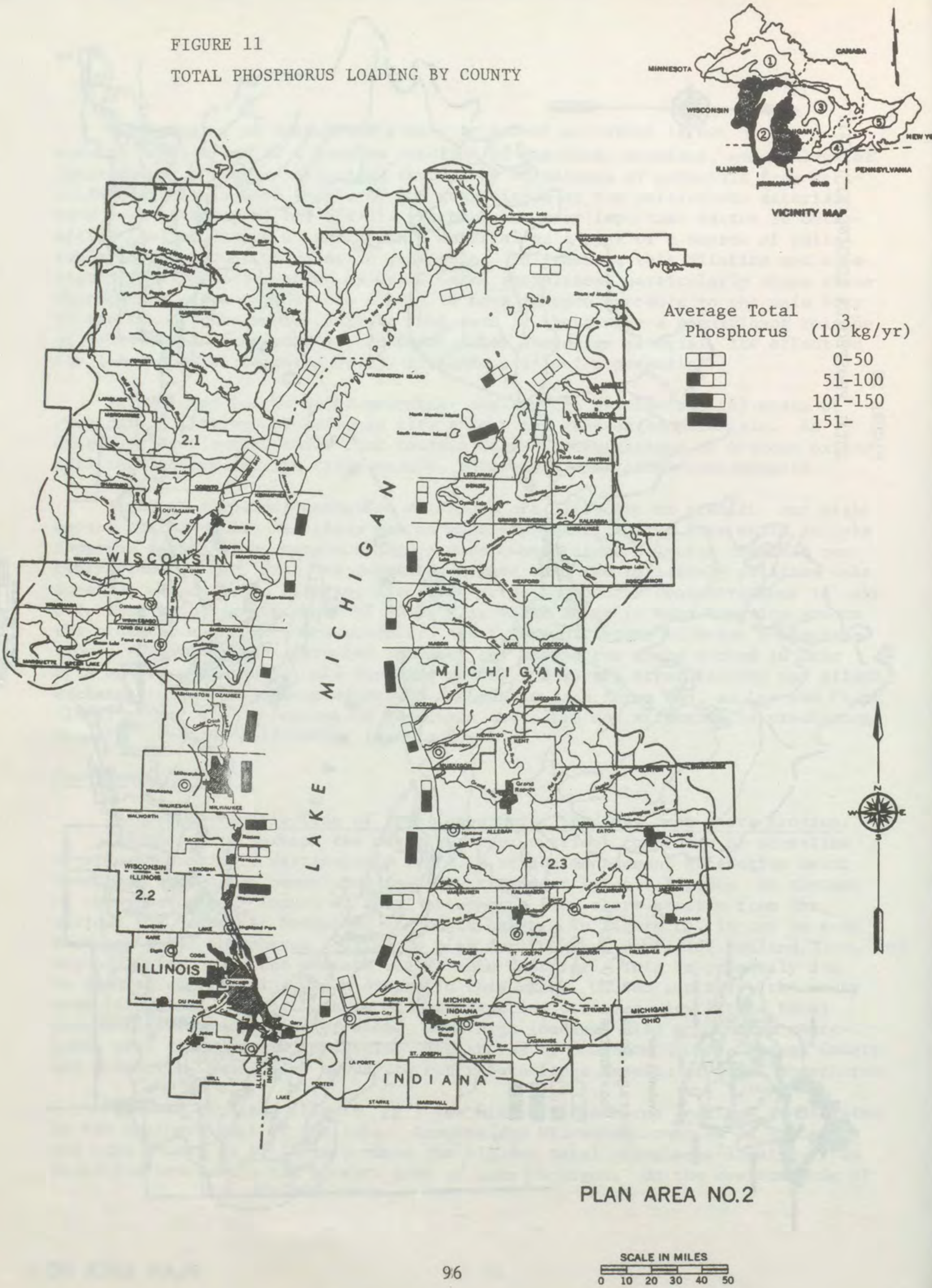


FIGURE 12

TOTAL PHOSPHORUS LOADING BY COUNTY

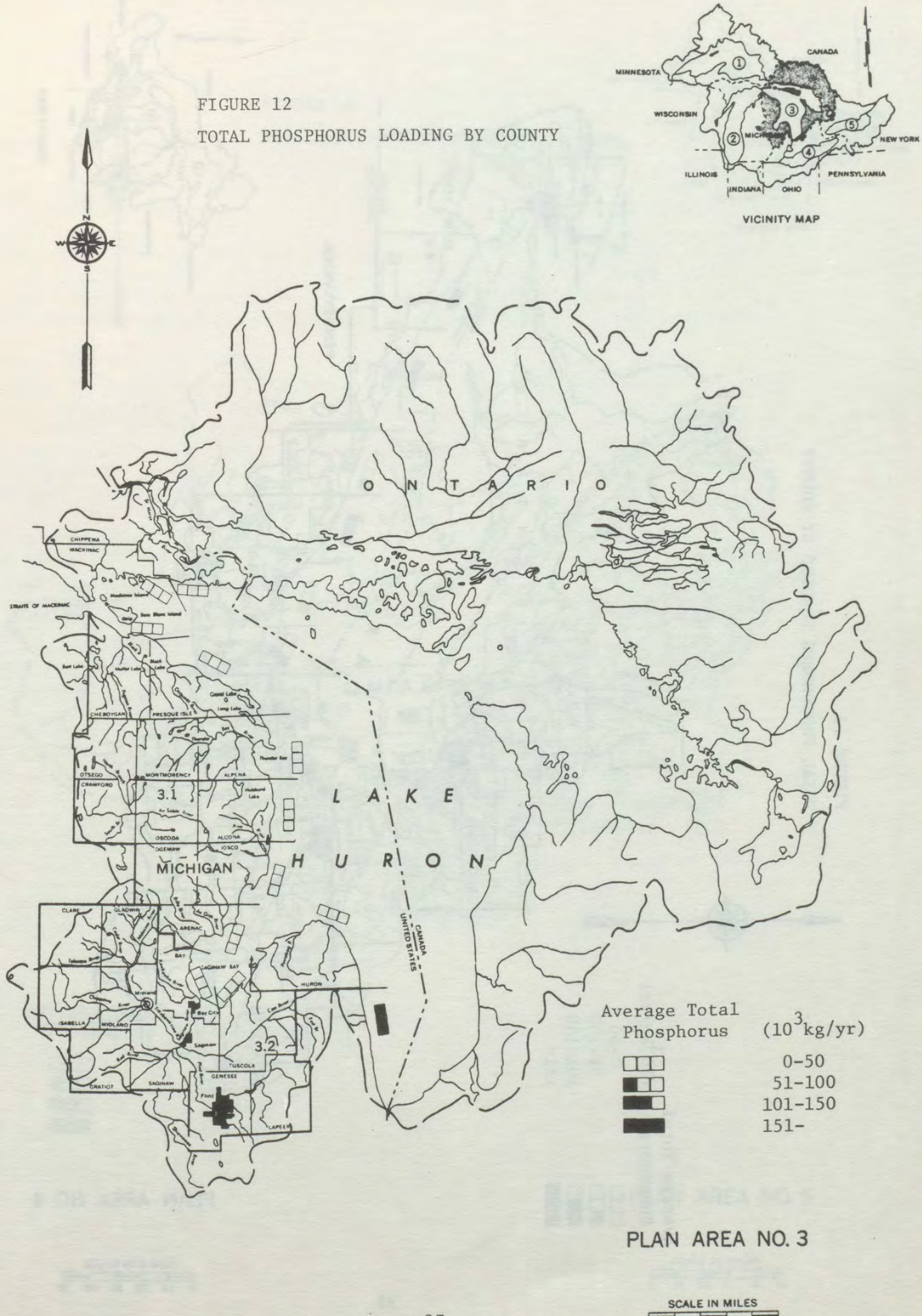


FIGURE 13

TOTAL PHOSPHORUS LOADING BY COUNTY

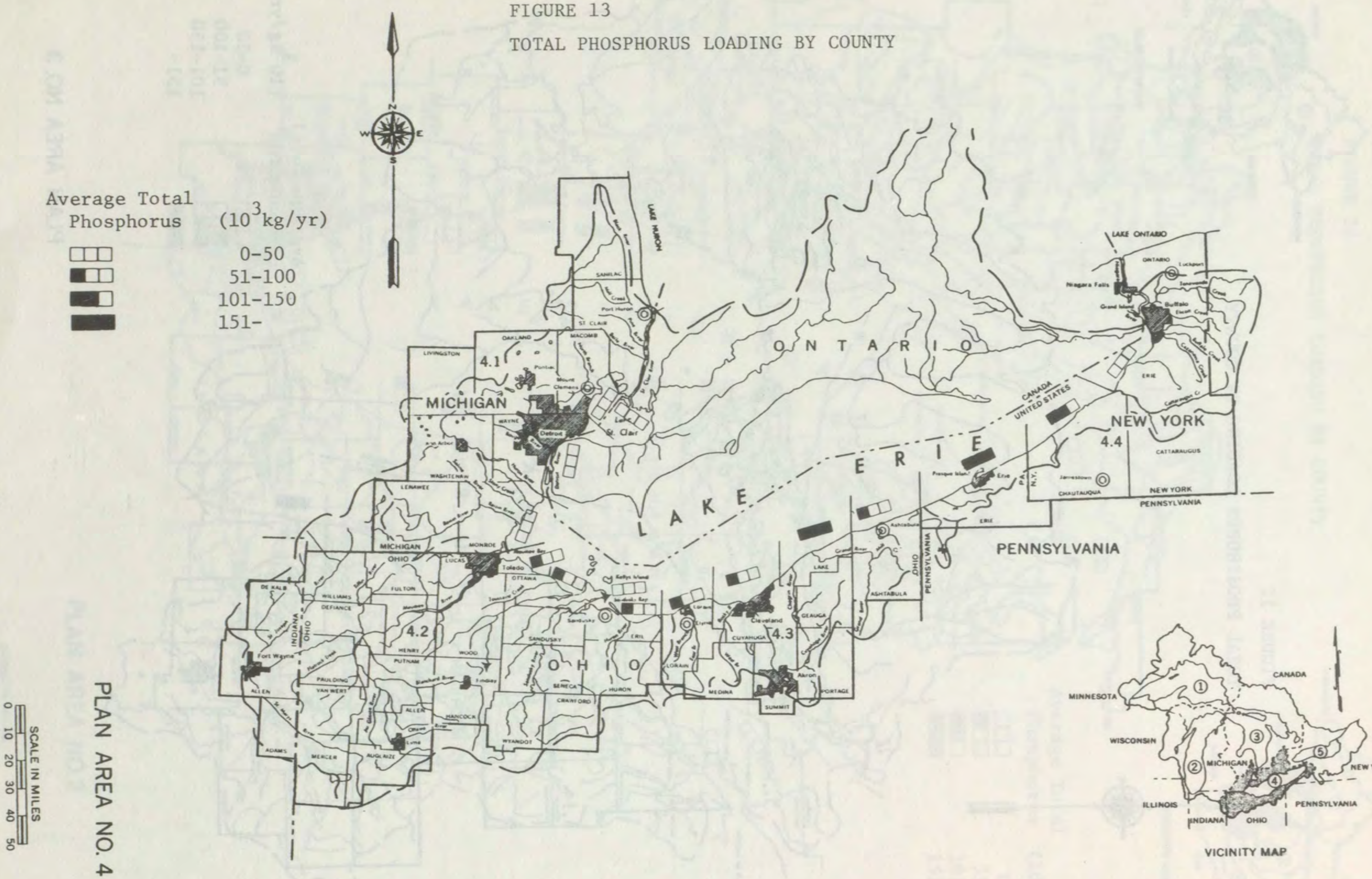
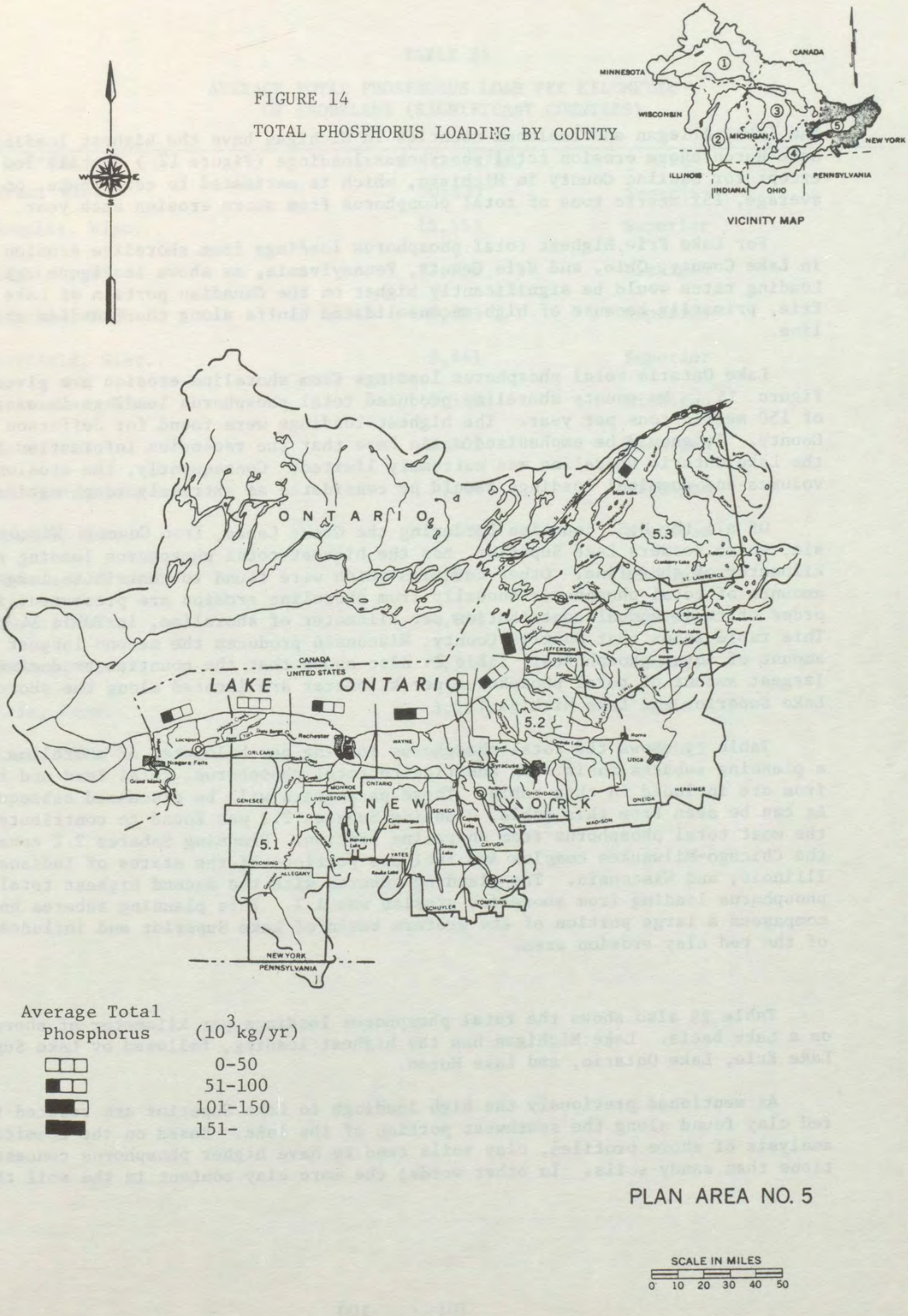


FIGURE 14

TOTAL PHOSPHORUS LOADING BY COUNTY



the Lake, Allegan and Leelanau counties in Michigan have the highest loadings. Lake Huron shore erosion total phosphorus loadings (Figure 12) are all low except for Sanilac County in Michigan, which is estimated to contribute, on the average, 151 metric tons of total phosphorus from shore erosion each year.

For Lake Erie, highest total phosphorus loadings from shoreline erosion occur in Lake County, Ohio, and Erie County, Pennsylvania, as shown in Figure 13 . Loading rates would be significantly higher on the Canadian portion of Lake Erie, primarily because of high unconsolidated bluffs along the Canadian shoreline.

Lake Ontario total phosphorus loadings from shoreline erosion are given in Figure 14 . No county shoreline produced total phosphorus loadings in excess of 150 metric tons per year. The highest loadings were found for Jefferson County. It should be emphasized again here that the recession information for the Lake Ontario shoreline was extremely limited. Consequently, the erosion volumes and chemical loadings should be considered as extremely rough estimates.

Of all the U.S. counties bordering the Great Lakes, Iron County, Wisconsin, which borders Lake Superior, has the highest total phosphorus loading per kilometer of shoreline. Other counties which were found to contribute large amounts of total phosphorus annually from shoreline erosion are presented, in order of their annual contribution per kilometer of shoreline, in Table 24 . This table shows that Douglas County, Wisconsin produces the second largest amount of total phosphorus. Table 24 also shows that the counties producing the largest amount of total phosphorus per kilometer are located along the shores of Lake Superior and Lake Michigan.

Table 25 shows the total phosphorus loading per kilometer of shoreline on a planning subarea basis. In addition to total phosphorus, total lead and total iron are included in this table. These parameters will be discussed subsequently. As can be seen from this table, Planning Subarea 2.2 was found to contribute the most total phosphorus from shoreline erosion. Planning Subarea 2.2 covers the Chicago-Milwaukee complex and includes portions of the states of Indiana, Illinois, and Wisconsin. The planning subarea with the second highest total phosphorus loading from shoreline erosion was 1.1. This planning subarea encompasses a large portion of the western basin of Lake Superior and includes much of the red clay erosion area.

Table 25 also shows the total phosphorus loadings per kilometer of shoreline on a Lake basis. Lake Michigan has the highest loading, followed by Lake Superior, Lake Erie, Lake Ontario, and Lake Huron.

As mentioned previously the high loadings to Lake Superior are related to the red clay found along the southwest portion of the lake. Based on the chemical analysis of shore profiles, clay soils tend to have higher phosphorus concentrations than sandy soils. In other words, the more clay content in the soil the

TABLE 24

AVERAGE TOTAL PHOSPHORUS LOAD PER KILOMETER OF SHORELINE (SIGNIFICANT COUNTIES)

County	rate (kg/yr/km)	Lake
Iron, Wisc.	30,833	Superior
Douglas, Wisc.	16,553	Superior
Ozaukee, Wisc.	12,956	Michigan
Gogebic, Mich.	8,863	Superior
Bayfield, Wisc.	8,441	Superior
Milwaukee, Wisc.	7,510	Michigan
Lake, Ill.	5,702	Michigan
Allegan, Mich.	5,244	Michigan
Racine, Wisc.	5,038	Michigan
Kewaunee, Wisc.	4,857	Michigan
Barga, Mich.	4,074	Superior
Oceana, Mich.	3,750	Michigan
Erie, Penn.	3,590	Erie
Lake, Ohio	3,469	Erie

TABLE 25

AVERAGE CHEMICAL LOAD PER KILOMETER OF U.S. SHORELINE (kg/yr/km)

Total Phosphorus			Total Lead			Total Iron		
PSA	Rate	Lake	PSA	Rate	Lake	PSA	Rate	Lake
2.2	4,698	M	2.2	344	M	1.1	298,791	S
1.1	4,132	S	1.1	234	S	2.2	239,039	M
2.3	3,119	M	4.4	159	E	2.3	171,852	M
4.4	2,301	E	4.3	159	E	4.3	128,006	E
4.3	2,293	E	2.3	153	M	4.4	111,869	E
1.2	1,664	S	1.2	127	S	1.2	78,084	S
5.2	1,600	O	5.2	123	O	5.2	7[illegible],677	O
2.4	1,042	M	2.4	60	M	4.2	59,023	E
4.2	907	E	5.1	59	O	2.4	54,886	M
5.1	782	O	4.2	56	E	5.1	35,782	O
3.2	699	H	3.2	51	H	3.2	32,622	H
2.1	663	M	2.1	50	M	2.1	31,196	M
5.3	363	O	5.3	16	O	5.3	21,807	O
4.1	196	E	4.1	8	E	4.1	13,748	E
3.1	102	H	3.1	4	H	3.1	5,406	H
Loading Rate By Lake								
1	2,546	Superior	1	165	Superior	1	157,003	Superior
2	1,671	Michigan	2	108	Michigan	2	86,504	Michigan
4	1,274	Erie	4	85	Erie	4	70,585	Erie
5	685	Ontario	5	59	Ontario	5	34,479	Ontario
3	277	Huron	3	18	Huron	3	13,379	Huron

To Convert from	To	Multiply by
Kilograms per year per kilometer (kg/yr/km)	pounds per year per mile (lb/yr/mi)	3.547

more phosphorus is likely to be found. This can best be seen by examining the Lake Superior and Lake Michigan data in Tables 18 and 20 (given previously) and Table 26 which shows the volume of each soil texture eroded from the five Lakes. Table 18 indicates that the average erosion rate for Lake Michigan is twice that of Lake Superior. However, since 75 percent of the volume eroded into Lake Michigan is sand (Table 26), compared to an 83 percent loam/clay content (which has a higher phosphorus concentration than sand) into Lake Superior, the total phosphorus loads in Table 20 for both of these Lakes are about equal.

Comparison of Total Phosphours Loadings from Shoreline Erosion With Other Sources. In order to appraise the relative importance of the phosphorus loadings from shoreline erosion, Table 27 was prepared which compares the average, maximum and minimum loadings from shoreline erosion with other pollution sources. Data is presented for the total Great Lakes, as well as on an individual Lake basis.

As Table 27 shows, the average total phosphorus input from shoreline erosion is similar and in some cases greater than the loading derived from tributaries. Tributary input includes both the non-point source input as well as the point source input. For the total Great Lakes the shore erosion loading is about the same as the input from tributaries. In Lake Superior shore erosion contributes several times more total phosphorus than the tributaries. Lake Michigan has a tributary input of about the same order of magnitude as the total phosphorus input from shore erosion. Both Lake Huron and Lake Ontario have higher total phosphorus loadings from the tributaries than from shore erosion. Lake Erie loading from the U.S. portion of the shoreline is also less than the tributary input. Nonetheless, in all cases, the shoreline erosion input is significant. When maximum shoreline total phosphorus inputs are considered, which may be closer to the actual case currently, the loadings are even more significant.

Shoreline erosion is more significant than atmospheric inputs in terms of total phosphorus for all lakes except Huron and Ontario. Compared to direct municipal inputs shoreline erosion inputs are higher except for Lakes Erie and Ontario. Direct industrial inputs are much less than the total phosphorus loadings from shoreline erosion for all the Lakes.

Overall, it appears that shoreline erosion can contribute on the order of 25 percent of the total phosphorus loadings from all sources to the Great Lakes. This is about the same percentage of the total load as contributed by tributary loadings (including rural and urban runoff, as well as point source discharges into tributaries). These large loadings are unimportant to the lake, however, unless a significant portion of the total phosphorus is available for uptake by the biota.

Availability of Phosphorus Derived from Shoreline Erosion. The impact of the total phosphorus contribution from shoreline erosion is of course dependent on the fraction of the total phosphorus that is available for uptake by biota. As was discussed in considerable detail in a previous section, extractable phosphorus (0.05 N HCl extraction) loadings were also calculated (See Table 20). The average extractable phosphorus loadings are about 45 percent of the average total

TABLE 26

AMOUNT OF SOIL TYPES ERODED FROM U.S. GREAT LAKES SHORELINE

Lake	Volume[a] (10^3 m^3/yr)			Percent		
	Sand	Loam	Clay	Sand	Loam	Clay
Lake Superior	748	1,870	1,720	17	43	40
Lake Michigan	6,282	1,926	168	75	23	2
Lake Huron	295	223	0	57	43	0
Lake Erie	671	610	244	44	40	16
Lake Ontario	92	451	67	15	74	11
Total Basin	8,088	5,080	2,016	53	34	13

To Convert from	To	Multiply By
cubic meters (m^3)	cubic feet (ft^3)	35.319

a Based on average erosion rate

TABLE 27

TOTAL PHOSPHORUS LOADING DATA (Metric tons/year)

Source		Total Great Lakes	Lake Superior	Lake Michigan	Lake Huron	Lake Erie	Lake Ontario
Tributaries, U.S.[a]		10,868	647	4,231	1,247	3,625	1,118
U.S.		-	-	-	-	12,482[b]	2,077[c,d]
U.S. & Canada[e]		-	2,832	-	4,417	-	-
Atmosphere		4,965	799[e]	1,000[f]	620[e]	900[b]	1,646[c]
Direct Municipal U.S.[a]		8,802	34	1,067	20	6,574	1,107
U.S.		-	-	-	-	-	607[c]
U.S. & Canada[e]		-	132	-	190	-	-
Direct Industry U.S.[a]		253	0	61	62	54	76
U.S. & Canada[e]		-	99	-	81	-	-
Shore Erosion U.S.	Avg.	9,349	3,781	3,711	295	1,024	538
	Max.	15,933	6,087	6,369	600	1,892	985
	Min.	3,938	1,569	1,692	114	376	187

To Convert From	To	Multiply by
Metric Tons	English Short Tons	1.102

[a] IJC Surveillance Sub-Committee (1975) does not include loads from upstream Lakes (i.e., St. Marys River or Detroit River, or Niagara River)

[b] U.S. Army Corps (1975) Does not include Detroit River

[c] Casey and Salbach (1974)

[d] Does not include Niagara River (7,607 metric tons/year) or St. Lawrence River (7,869 metric tons/year)

[e] IJC, ULRG (1976) does not include St. Marys River Load

[f] Murphy and Doskey (1975)

phosphorus loadings for the entire U.S. shoreline of the Great Lakes. There is some variation for individual lake coastlines. Lake Superior samples have extractable phosphorus concentrations equal to about 53 percent of the total phosphorus while extractable phosphorus in Lake Huron samples equal about 35 percent of the total phosphorus. This indicates that a significant fraction of the total phosphorus could be extracted with 0.05 N HCl. The interpretation of the acid extractable data was dealt with previously, but in general the extraction probably measures an upper limit of the fraction of the total phosphorus that is likely to be available for biological uptake.

A number of factors influence the availability of the phosphorus whether it be short term availability or long term availability. In many cases particulate material may not release phosphorus immediately upon entering the lake water, but phosphorus could be released at a later time under continuous leaching pressure or perhaps as a result of a change in environmental conditions. For example, if phosphorus is released at a very slow rate so that is difficult to measure over a short period of time, one might conclude that particulate material does not contain significant available phosphorus. However, if one measures this release over long periods of time, a significant total release could occur which may have an effect on water quality. Similarly, particulate material exposed to oxic lake water conditions may not release much phosphorus. If the particulate material is subsequently exposed to a different environmental condition such as a change in solution pH, a different Eh, or a different solution phosphorus concentration, some phosphorus release could occur. As an example, if particulate material eroded from the western shore of Lake Erie was transported to the central basin where anoxic conditions usually occur each summer, release of phosphorus could occur at that time. If in other Great Lakes, localized anoxic conditions occur, phosphorus release could occur in substantial amounts. This would be particularly true if the phosphorus were associated with particulate material in connection with the hydrous metal oxides.

It is also possible for the water column to be oxic while anoxic conditions exist at the sediment/water interface. Under these conditions even though the overlying water is oxic, release could take place after the particulate material from shoreline erosion has settled onto the bottom (Sonzogni et al., 1976). Some release of phosphorus from particulate material could also occur at the sediment under oxic conditions. This could occur as a result of microbrial action on the soil particles. Soils rich in organic matter would be particularly important in such instances. The importance of release of phosphorus from lake sediments under oxic conditions has been discussed by Lee et al., 1976).

Another important effect on the potential release of phosphorus from solids is the degree of mixing of the solids. Lee et al. (1975) in their review of mechanisms by which phosphorus can be released from disposal of dredged material, has discussed the importance of mixing on this release from particulate material. It would appear that mixing is more important than molecular diffusion in the transport of phosphorus across a solid water interface. In general, laboratory experiments show that phosphorus release is increased when sediment or particulate samples are agitated. Since shoreline erosion occurs almost exclusively during periods of high wind and storm (i.e., high mixing) conditions, newly eroded material is likely highly mixed with the nearshore waters. The length of time the shoreline material remains dispersed in the water would depend on many factors (such as the particle size and density of the material, or the length of the storm), but at least during this time the hydrodynamics would not likely limit phosphorus release from the material.

Another possible factor that has been discussed as a mechanism controlling the release of phosphorus from settled solids in lakes is the capacity of the sediments to buffer overlying water phosphorus concentrations. According to this theory, phosphorus is removed from the water column or released from the sediments until an "equilibrium" concentration is reached. However, it is doubtful that sediment phosphorus concentrations have a major buffering effect, at least not to the extent that it controls phosphorus release or uptake. As discussed in an earlier section, sediment phosphorus concentrations do not seem to control movement of phosphorus across the sediment-water interface. Sonzogni et al. (1976) have presented evidence which indicates that sediments did not act as phosphorus buffers in the inland lakes in which they studied.

Bahnick (1975) conducted some leaching studies of red clay soils from the western Lake Superior area. He found that, based on a seven week leaching study (using Lake Superior water as the leachate), 0.030 ± .010 mg of orthophosphate (as PO_4) per g of clay soil sample and 0.036 ± 0.020 mg of total soluble phosphorus per g of soil was released. Phosphorus was released rapidly from the samples and with the rate of release declining to near zero (within detection limits) within one day. Deionized water resulted in increased releases. Similarly, a decrease in pH resulted in an increase in the amount of phosphorus released. Temperature was found to have no significant effect on the release. In general Bahnick found a release of 10 to 60 µg P/g soil occured under Lake Superior conditions (oxic). Surprisingly, he did find a lower release of phosphorus under anoxic conditions. It should be mentioned that the clay soils used for the leaching studies were taken from Great Lakes shoreline locations as well as streambanks composed of erodible red clay.

Bahnick (1975) also conducted a number of other studies in which he tried to estimate the exchange of phosphorus between water and soil at various soil-to-solution ratios. He concluded from these studies that at the natural solution concentrations of phosphorus in Lake Superior, orthophosphate would be released from the soil samples. Using a value for the amount of shoreline soil material eroded per year to Lake Superior of 8×10^6 metric tons per year (somewhat less than the value obtained in this study), Bahnick estimated an annual orthophosphorus (as P) input to Lake Superior of 80 (plus or minus 25) metric tons per year. He estimated the total soluble phosphorus input to be 280 (plus or minus 160) metric tons per year from shoreline erosion. Importantly, he indicated that his estimated input value was probably a lower limit to the actual input. Since the eroded clay material will probably attain low soil-to-solution ratios due to dispersal in the lake water during the erosion process, phosphorus release would be encouraged based on his studies. Also, orthophosphorus released from the clay particles would be taken up quickly by organisms in the Lake Superior water. This, in turn, would lower the solution concentration and thus cause a greater release of phosphorus to the water. He also indicated that it was possible that some organisms may directly remove orthophosphorus upon contact with the clay particles. These effects were not accounted for in the laboratory leaching studies.

Given the results of Bahnick (1975) and the results of this study, it is now possible to further define the available phosphorus loading from shoreline erosion for Lake Superior. Bahnick's loading of 80 metric tons per year was considered to be the lower limit of orthophosphorus (all available) loading from shoreline erosion. As discussed previously, the extractable phosphorus loading calculated for Lake Superior in this study was found to be about 2000 metric tons per year and this was thought (as discussed earlier) to be an upper limit to available phosphorus loading. The actual available phosphorus loading to Lake Superior, therefore, likely lies between about 80 and 2000 metric tons per year. This loading is certainly significant relative to other nutrient sources to Lake Superior. For example, the mean annual reactive phosphorus loading (as P) calculated for Lake Superior from tributaries by the Upper Lakes Reference Group (1976) was found to be 642 metric tons per year. Although the total available phosphorus is likely to be somewhat higher than just the reactive phosphorus (essentially the same as orthophosphorus), it would appear that shore erosion may be contributing about the same order of magnitude of available phosphorus as is derived from tributary loadings.

Unfortunately, leaching type studies on other soils for other lake shorelines are not available. However, given the leaching results of Bahnick (1975) of approximately 80 metric tons per year and the extractable phosphorus loading to Lake Superior from this study of about 2000 metric tons per year, it can be seen that the lower limit is slightly over 4 percent of the upper limit. Using this relationship for the other lakes, the available phosphorus loading for Lake Michigan and Lake Huron would range from about 60 to 1500 and 4 to 100 metric tons per year, respectively, and the range for Lake Erie and Lake Ontario would be from about 20 to 500 and about 8 to 200 metric tons per year, respectively. Similarly, for the total U.S. shoreline, the available phosphorus loading from shoreline erosion would range from about 160 to 4,000 metric tons per year. These ranges would, of course, be higher if the extractable phosphorus loadings for maximum erosion were used. It should be realized that these ranges are predicated on gross assumptions and are only used here to illustrate the general order of magnitude of available phosphorus loading that is possible. Further, most of the soils on the Great Lakes shorelines are sandy and how much phosphorus might be leached from them is not known, but it is likely to be lower than that leached from clay soils. Also, phosphorus solution concentrations are higher for the lower Great Lakes which may consequently restrict release of phosphorus.

In another study, the U.S. Army Corps of Engineers (1975) has estimated the phosphorus loading from shoreline erosion to Lake Erie. The loadings are based on the work of Carter (1975). They indicated that a very large amount of total phosphorus will enter the lake from shoreline erosion, particularly from the Canadian shoreline. However, based on Canadian studies by Williams et al. (1976) and Kemp et al. (1976), it was concluded that phosphorus from shoreline erosion is mainly bound as appatite. Appatite phosphorus is generally not considered to be an available source of phosphorus to biota and thus was not considered further as a nutrient source to Lake Erie. It would seem that even though the available phosphorus portion from the eroded material is relatively small compared to total phosphorus loading, the available phosphorus loading still may be significant in terms of overall loading to the lake. Leaching tests using leaching solutions with phosphorus concentrations similar to Lake Erie waters may provide insight into the availability of phosphorus associated with shoreline material eroded into Lake Erie and the lower lakes in general.

Other Nutrients

Other than phosphorus, nitrogen is generally considered to be the most important nutrient affecting lake productivity. Although extractable nitrate and ammonia were measured on shoreline samples (see previous discussion), only total nitrogen loadings were calculated. The nitrogen levels measured reflect the natural variability of nitrogen in soils and as a result the calculated total nitrogen loadings should be viewed with considerable skepticism. The actual total nitrogen loading could conceivably differ from the loading reported by a few orders of magnitude.

Bahnick (1975) observed little total nitrogen being released by red clay soils in laboratory leaching tests. He estimated that the leachable total Kjeldahl nitrogen loading to Lake Superior from shoreline erosion would be less than 1600 metric tons per year. In this study, it was estimated that the total Kjeldahl nitrogen loading to Lake Superior (based on bulk composition) was about 6000 metric tons per year. Total nitrogen loadings to Lake Superior from the tributaries is estimated to be about 36,500 metric tons per year for Lake Superior (Upper Lakes Reference Group, 1976). Atmospheric loading of total nitrogen was even higher. In both cases, these values are significantly higher than was estimated for shoreline erosion.

Nitrate and ammonia loadings were not calculated in this study, but Bahnick (1975) estimated that shoreline erosion contributes about 400 (plus or minus 400) metric tons per year of leachable nitrate nitrogen to Lake Superior. Again, it should be emphasized that these data were based on time dependent leaching studies.

The release of ammonia from solids is of particular concern, since ammonia can be toxic to aquatic life. This has prompted review of the toxic effects of ammonia on aquatic life in association with dredging and dredged material disposal (Lee et al., 1975). Ammonia concentrations would tend to be high in areas of high biological activity or in areas of gross pollution. However, it seems unlikely that ammonia concentrations in shoreline material would have any toxic effects in the lake. Plumb and Lee (1976) found little release of ammonia from taconite tailings disposed in Lake Superior. They concluded that this was the result of the fact that sediments were relatively inert and contained few nutrients. While it would not seem likely that ammonia would be significant as a toxicant, low levels of ammonia released could have an effect as a plant nutrient.

Silica is considered to be a nutrient essential for diatom growth and it may play a major role in the biological make up of the Great Lakes. Schelske and Stoermer (1971) contend that silica limitation favors the growth of less desirable algae, such as blue-green algae. Unfortunately, silica was not measured by EPA in this study. Obviously, there is a very large total silica load to the Great Lakes as a result of the erosion of sandy shorelines. The percent of the total silica that becomes dissolved, however, as a result of shoreline erosion is not known. Carter (1975) presented data on the total silica loadings to Lake Erie from shoreline erosion, which was about 25 percent of the total samples analyzed. No information is available on the percent of the total silica load which can be utilized by algae in the lake, however.

Organic carbon was measured from shoreline samples but loadings were not calculated. Particulate organic carbon contributed to the lake from shoreline erosion may exert an oxygen demand although the importance of the oxygen demand of eroded shoreline material is not known. It is not likely to be important unless the eroded material settles in large quantities in a bay with restricted circulation or in some other area in which mixing rates with the atmosphere or open water are reduced. Based on some preliminary U.S. Task D studies, there does seem to be a significant amount of eroded shoreline material coming from the western basin of Lake Erie which apparently moves out toward the central basin. This material may be settling in the central basin and exerting an oxygen demand which contributes to the anoxic conditions that frequently develop in the central basin.

Metals and Other Elemental Parameters

The potential effect of various forms of metals on the biota of the Great Lakes, as well as on people who drink water or consume fish from the Great Lakes, is of considerable concern. The international Joint Commission has been trying to determine the potential availability of different forms of metals and set criteria for these metal forms. The present approach is that until more detailed knowledge is available on the toxicity of various forms of heavy metals, criteria should be set for total heavy metal concentrations. Recently, the Water Quality Board has published Proposed New and Revised Water Quality Objectives (Great Lakes Water Quality Board, 1976). This report proposed specific objectives for arsenic, cadmium, chromium, lead, mercury, selenium, and zinc. Importantly, all of these objectives are based on total quantities of metals. Consequently, the shore erosion loadings of total forms of metals, as well as the extracable fraction, need to be considered. Helmke, et al. (1976) has reviewed some of the processes affecting the availability of trace metals. They cite three different phases in which the components of the total amount of an element in the sediment may be found. These include a non-exchangable phase, an exchangable phase, and a water phase. These phases are thought to be in a steady state condition with each other. Reactions between the exchangable and non-exchangable phases are thought to be quite slow (on the order of years) while reactions between the exchangable and soluble phases are rapid (on the order of hours or days). Material in the fixed phase is thought to be unavailable to organisms in the water column under normal conditions. Since the relative proportion of a metal within these phases is dependent on a number of factors, not the least of which is the method of measurement, it is difficult to determine the available fraction. It is for this reason that total measurements are often considered, as is the case for the new proposed water quality standards, for certain metals rather than in available form.

The difficulty in trying to interpret the effect of metals on the environment is further exemplified by the studies of Lopez (1973). He studied the metals content of bottom sediments and overlying water in Torch Lake, located on the copper rich Keewanaw Peninsula of Michigan near Lake Superior. This lake has received large amounts of copper mine tailings and high levels of copper are found in Torch Lake waters. This copper apparently exists in a relatively non-toxic form since there are, according to Lopez (1973), substantial amounts of phytoplankton and fish in the lake. This occurs despite the fact that the concentrations of copper (in the range of 25-100 micrograms per liter) are known to cause deleterious effects on aquatic life. Perhaps the copper is complexed with organics and thus is not available for biological uptake. This example points to the fact that despite high metal concentrations the potential effect on the lake is not always obvious. Other examples may be found in Lee and Plum (1974).

Helmke et al. (1976) in their study of the effects of dredged material disposal in Lake Superior determined that concentrations of 160 to 250 parts per million (ppm) zinc, 65 to 88 ppm copper, and 0.0 to 0.4 ppm mercury would not affect concentrations of these elements in organisms (in a companion study Magnuson et al. (1976) have reported in detail on the environmental effects of metal contamination from dredged disposal in Lake Superior). Except for one isolated instance, all zinc concentrations measured on the shoreline samples were below the 160 to 250 ppm range. Similarly, copper concentrations in the shoreline profiles were below this range and all mercury measurements were below detection limits. Thus, based on the above study, it would appear that neither the zinc, copper or mercury concentrations in eroded shoreline material affects concentrations of these elements in organisms.

Cogley (1974) has calculated loadings of lead to Lake Michigan from the Chicago area. Of the different sources he considered, he found that most of the load to southern Lake Michigan was derived from atmospheric transport of automotive lead aerosols. Precipitation washout from the atmosphere was the most important mechanism for lead input to Lake Michigan. However, he did not consider shoreline erosion as a lead source. He estimated that about 1,630 metric tons per year of lead was contributed to the southern basin, mainly from atmospheric precipitation washout. In this study it was estimated that for all of Lake Michigan approximately 240 metric tons per year of total lead is contributed by shore erosion.

Bahnick (1975) estimated the input of various metals and other elements from shoreline eorsion based on his leaching studies of red clay soils. Table 28 shows the metal loadings from shoreline erosion estimated for Lake Superior by Bahnick (1975) with the estimates obtained from this study. Bahnick (1975) found that whether a metal is released or, in some cases, is taken up by clay soils is a function of the concentration of the metal in the aqueous system. He found that copper has little tendency to be released from clay. Clay particles can remove copper from solution when water contains high copper concentrations. For example, he found that soil samples suspended in Lake Superior waters at a concentration of 10 parts per billion (ppb) copper would result in the removal of 350 grams of copper per ton of the clay. This information is important from the standpoint that there is a significant amount of copper tailings and copper-rich sediment that finds its way into Lake Superior.

TABLE 28 SHORELINE EROSION LOADINGS TO LAKE SUPERIOR BASED ON THE LEACHING STUDIES OF BAHNICK AND RESULTS OF THIS STUDY

	metric tons/year		
	Bahnick (1975)	This Study	
	Leachable[1]	Total	Extractable
Copper	3.0 ± 1		
Manganese	56	4,326	876
Cadmium	0.008		
Zinc	8		
Lead	1		
Chromium	8		
Aluminum	76 ± 50	114,275	
Iron	64 ± 10	218,437	2,068
Mercury	0.08		

1. Lake Superior Water used as leachate

Table 28 shows that the manganese loading to Lake Superior from shoreline erosion as calculated by Bahnick (1975) was considerably smaller than the loading estimated in this study It should be realized that the extractable loading for manganese probably represents an upper limit to the amount that can be released while Bahnick's data is probably a lower limit. Bahnick's data was based on a short-term leaching study. The release of manganese to Lake Superior water is particularly important since Shapiro (personal communication, 1976) has indicated that manganese may be a limiting trace nutrient for Lake Superior algae.

Table 29 is a comparison of estimates of several elemental loadings from shoreline erosion to Lake Superior and Lake Huron with tributary loading estimates made by the Upper Lakes Reference Group (1976). Elements compared include calcium, iron, lead,magnesium, and manganese. Tributary loadings are generally greater than shoreline erosion loadings except for iron and manganese. Total iron loadings for Lake Superior are considerably higher than tributary loadings. However, Lake Huron shore erosion loadings of iron are less than those derived from tributaries. In all cases, extractable loadings (when reported) are considerably less than the total loadings for the tributaries. It should

TABLE 29

COMPARISON OF SHORELINE EROSION LOADINGS AND TRIBUTARY LOADINGS INTO LAKE SUPERIOR AND LAKE HURON

(metric tons/year)

	Total Tributary[1] Superior	Total Tributary[1] Huron (Main Body)	U.S. Shoreline Erosion Superior Total	U.S. Shoreline Erosion Superior Extractable	U.S. Shoreline Erosion Huron (Main Body) Total	U.S. Shoreline Erosion Huron (Main Body) Extractable
Calcium	1,190,000	1,090,000	256,000		22,000	
Iron	65,335	23,300	233,000	2,200	14,000	160
Lead	1,110	260	240		120	
Magnesium	351,000	343,000	149,000	40,000	11,000	4,000
Manganese	2,416	471	4,500	900	330	70

1. Based on Upper Lakes Reference Group Study (1976); includes both U.S. and Canadian total tributary inputs (including point inputs to the tributaries)

be realized that the tributary loadings as well as shore erosion loadings are not totally available biologically. For example, a large part of the iron and manganese carried into the lake through the tributaries is probably associated with particulate material.

Loadings of other trace toxic metals from shoreline erosion would likely be quite low based on the data on hand. Generally, highest loadings would probably be found in areas of the shoreline high in clay content, such as the red clay area of Lake Superior.

Atmospheric loadings generally contribute less chemicals (total forms) to the Great Lakes than shoreline erosion. Exceptions to this are some trace metals which may be primarily transported to the lake via the atmosphere. Lead is an example of such a trace element and has been previously discussed. It is important to note that atmospheric loadings are spread over the whole surface of the lake, while shoreline erosion loadings are confined to the nearshore or coastal zone areas. Thus, there is a somewhat greater tendency for dilution of atmospheric inputs compared to shoreline erosion inputs. Nonetheless, the dilution potential within the Great Lakes is still extremely great for both the coastal zone and the whole lake in general. On the other hand atmospheric inputs may be concentrated in surface films while the turbulence of the erosion process would tend to thoroughly mix shore erosion inputs.

It should be mentioned that the release of different metals from particulate material depends on many environmental factors, such as pH, Eh, and the concentration gradient between the solution and the solid phase (Forstner, 1976). Microbial activities can enhance release of metals by forming inorganic compounds capable of complexing metal ions, by influencing the physical properties and the pH-Eh conditions, and by converting inorganic metal compounds to organic molecules as a result of enzematic reactions. An example of the latter is transformation of inorganic mercury to organic mercury compounds. Factors which affect the release of phosphorus have been discussed in some detail previously, and since the same mechanisms generally apply to metals, the discussion will not be repeated here.

In general, it is not felt that metals associated with eroded shore materials are important as a source of pollutants to the Great Lakes. While the levels of the total forms of some metals may be significant relative to other sources, the amount of the total that is available to biota is probably low. Anthropogenic sources of metals have undoubtedly a much more important influence on the lake. However, if certain changes occur in the chemistry of the water, such as the development of anoxic conditions, the influence of metals contributed by shoreline erosion can be perhaps significant. Forstner (1976) has explained that the use of synthetic complexing agents, such as nitrilotriacetic acid (NTA), in detergents as a replacement for polyphosphates could perhaps increase the solubilization of heavy metals. This further indicates all material inputs on the lake can have an effect on the lake under certain environmental conditions.

Trace Organic Contaminants

As discussed earlier trace organic contaminants such as PCBs and pesticides were not detectible in the shoreline samples. Consequently, loadings of these compounds via shore erosion is not likely to be significant. On the contrary, the shoreline material added to Great Lakes waters may serve to remove organic contaminants from solution by sorption. The organics would be carried to the sediment as the shoreline material settles to the bottom of the lake.

REFERENCES

Armstrong, J.M., Seibel, E. and C.L. Alexander (1976). "Technical Report on Determination of Quantity and Quality of Great Lakes U.S. Shoreline Eroded Material", Pollution from Land Use Reference Group, International Joint Commission.

Bahnick, D.A. (1975). "Chemical Effects of Red Clays on Western Lake Superior", Center for Lake Superior Environmental Studies, University Wisconsin, Superior, 89 p.

Bannerman, R.T., Armstrong, D.E., Holdren, G.C. and R. F. Harris (1974). "Phosphorus Mobility in Lake Ontario Sediments" Proc. 17th Conf. Great Lakes Res., Internat. Assoc. Great Lakes Res., p. 158-178.

Black, C.A. (ed)(1965). "Methods of Soil Analysis" Part 2, American Society of Agronomy, Madison, Wisconsin.

Bortleson, G. C. and Lee, G.F. (1972). "Recent Sedimentary History of Lake Mendota, Wis.", Envir. Sci. and Tech., 6, 9, p. 799-808.

Boulden, R.S. (1975). "Canada-Ontario Great Lakes Shore Damage Survey", Environment Canada/Ontario Ministry of Natural Resources, 97 p.

Brady, N.C. (1974). The Nature and Property of Soils, 8th ed., Macmillan, New York, 639 p.

Brown, D.W., Pellegrim, C., Williams, S., and T.O. Kolbery (1973). "Shore Erosion in the Great Lakes-St. Lawrence System-Part 2" Task Force on Available Shore Erosion Information on the Great Lakes-St. Lawrence System, Canada Center for Inland Waters, 102 p.

Cairns, J., Jr., (1968). "Suspended Solids Standards for the Protection of Aquatic Organisms," 22nd Purdue Industrial Waste Conf., Purdue Univ., Eng. Bulletin 129, p. 16-27.

Carter, C. H. (1975). "Sediment Load Measurements Along the U.S. Shore of Lake Erie", Ohio Division of Geological Survey, U.S. Army Corps of Engineers (Buffalo District) Contract DACW 49-75-C-0031, 83 p.

Casey, D.J. and Solbach, S.E. (1974). "IFYGL Stream Materials Balance Study" Proc. 17th Conf. Great Lakes Res., p. 668-681.

Cogley, A.C. (1974). "Large-Scale Mass Balance for Lead in Southern Lake Michigan", Water Resources Center Research Report No. 85, Univ. of Illinois, Urbana, 15 p.

Cordene, A.J. and Kelley, D.W. (1961). "The Influence of Inorganic Sediment on the Aquatic Life of Streams", California Fish and Game, 47, p. 189-228.

Cowen, W.F. (1974). "Phosphorus Availability in Urban Runoff and Lake Ontario Tributary Waters", Ph.D. Thesis, Water Chemistry Program, Univ. of Wisconsin, Madison.

Forstner, U. (1976). "Forms and Sediment Associations of Trace Metals", Paper Presented at Fluvial Transport of Sediment-Associated Nutrients and Contaminants Workshop, Pollution from Land Use Activities Reference Group, International Joint Commission, Kitchner, Ontario, 14 p.

Great Lakes Basin Commission (1975). Great Lakes Basin Framework Study, Great Lakes Basin Commission, Ann Arbor, Michigan 105 p. plus 23 appendices.

Great Lakes Water Quality Board (1976). "Proposed New and Revised Water Quality Objectives", International Joint Commission, Windsor, Ontario, 182 p.

Helmke, P.A., Koons, R.D. and I.K. Iskandar (1976). "An Assessment of the Environmental Effects of Dredged Material Disposal in Lake Superior: the Volume V Trace Element Study", Marine Studies Center, Institute for Environmental Studies, University of Wisconsin, Madison, 148 p.

Herdendorf, C.E. (1976). "Effect of Maumee River Input on Lake Erie Water Quality", Preliminary Data Report of March 1975 Pilot Study, Center for Lake Erie Area Research, Ohio State University.

Hollis, E.H., Boone, J.G., DeRose, C.R. and G.J. Murphy (1964). "Literature Review on the Effects of Turbidity and Siltation on Aquatic Life", Dept. Chesapeake Bay Affairs, Maryland Fish and Wildlife Admin., Annapolis, Md., 20 p.

IJC Surveillance Subcommittee (1975). "Annual Report of the Surveillance Subcommittee", Appendix B, Great Lakes Water Quality Fourth Annual Report, International Joint Commission, Windsor, Ontario, 255 p.

Jackson, M.L. (1973). "Soil Chemical Analysis-Advanced Course", Department of Soil Science, University of Wisconsin, Madison, Printed by the author.

Jenne, E.A. (1968) "Controls on Mn, Fe, Co, Ni, Cu, and Zn Concentrations in Soils and Water: the Significant Role of Hydrous Mn and Fe Oxides", Adv. Chem., 73, p. 337-387.

Jenne, E.A., Ball, J.W. and C. Simpson (1974). "Determination of Trace Metals in Sodium Dithionite-Citrate Extracts of Soils and Sediments by Atomic Adsorption", J. Environ. Qual., 3, p. 281-287.

Kemp, A.L.W., Thomas, R.L., Dell, C.I. and J.-M. Jaquet (1976). "Cultural Impact on the Geochemistry of Sediments in Lake Erie", J. Fish. Res. Bd. Canada, 33, 3, p. 440-462.

Lee, G.F. (1970). "Factors Affecting the Transfer of Materials Between Water and Sediment", Water Resources Center, University of Wisconsin, Madison, Occasional Paper No. 1, 50 p.

Lee, G.F. and Plumb, R.H. (1974). "Literature Review on Research Study for the Development of Dredged Material Disposal Criteria", U.S. Army Engineer Experiment Station Contract Report D-74-1, Vicksburg, Mississippi, 145 p.

Lee, G.F., Puvoni, M.D., Lopez, J.M., Mariani, G.M., Richardson, J.S., Homer, D.H. and F. Saleh (1975). "Research Study for the Development of Dredged Material Disposal Criteria", U.S. Army Engineer Waterways Experiment Station, Contract Report D-75-4, Vicksburg, Miss., 337 p.

Lee, G.F., Sonzogni, W.C. and R.D. Spear (1976). "Significance of Oxic vs. Anoxic Conditions for Lake Mendota Sediment Phosphorus Release", Proceedings of International Symposium on Sediment-Water Exchange Processes, Amsterdam, in publication.

Lopez, J.M. (1973). "Aqueous Environmental Chemistry of Cooper and Other Heavy Metals in Torch Lake and Selected Waters of the Keweenaw Peninsula Area of Lake Superior", M.S. Thesis, Univ. of Wisconsin, Madison.

Magnuson, J.J., Forbes, A. and R. Hall (1976). An Assessment of the Environmental Effects of Dredged Material Disposal in Lake Superior: Volume 3, Biological Studies, Marine Studies Center, Institute for Environmental Studies, Univ. of Wisconsin, Madison, 173 p.

May, E.B. (1973). "Environmental Effects of Hydraulic Dredging in Estuaries", Alabama Marine Resources Bulletin, 9, p. 1-85.

Mildner, W.F. (1974). "Assessment of Erosion and Sedimentation to the U.S. Portion of the Great Lakes Basin", Task A Report, Vol. I, Pollution from Land Use Activities Reference Group.

Murphy, T.J. and Dosbrey, P.V. (1975). "Inputs of Phosphorus from Precipitation to Lake Michigan", U.S. EPA Ecological Research Series, EPA-600/3-75-005, Environmental Research Laboratory, Duluth, Minn., 27 p.

Plumb, R.H. and Lee, G.F. (1975). "Response of Lake Superior Algae to Nutrients and Taconite Tailings", I.W.P.C.F.

Plumb, R.H. and Lee, G.F. (1976). "The Impact of Taconite Tailings on Dissolved Solids Concentrations in Lake Superior", in publication.

Ronan, R. (1975). "Simultaneous Analysis of Liquid Samples for Metals by Inductively Coupled Argon Plasma Atomic-Emission Spectroscopy (ICAP-AES)", U.S. Environmental Protection Agency, Region V, Chicago, 12 p. + tables.

Sagher, A. (1974). "Microbial Availability of Phosphorus in Lake Sediments", M.S. Thesis, Dept. of Soil Science, Univ. of Wisconsin, Madison.

Sagher, A., Harris, R.F. and D.E. Armstrong (1975). "Availability of Sediment Phosphorus to Microorganisms", Technical Report WIS WRC 75-10, Water Resources Center, University of Wisconsin, Madison.

Schelske, C.L., Stoermer, E.F. (1971). "Eutrophication, Silica Depletion, and Predicted Changes in Algal Quality in Lake Michigan", Science, 173, p. 423-424.

Schroeder, D. (1976). "Phosphorus Mobility in Runoff Waters from Agricultural Areas", Ph.D. Thesis, Water Chemistry, University of Wisconsin, Madison.

Seyers, J.K., Harris, R.F. and D.E. Armstrong (1973). "Phosphate Chemistry in Lake Sediments", I. Environ. Qual. 2, p. 1-14.

Shukla, S.S., Syers, J.K., Williams, J.D.H., Armstrong, D.E. and R.F. Harris (1971). "Sorption of Inorganic Phosphate by Lake Sediments", Soil Sci. Soc. Amer. Proc., 35, 244-249.

Sommers, L.E., Nelson, D.W., Monke, E.J., Beasley, D., Bottcher, A.D. and D. Kaminsky (1975). "Water Quality Monitoring in Black Creek Watershed" in Environmental Impact of Land Use on Water Quality, Black Creek Project Progress Report, Allen County Soil and Water Conservation District, p. 63-154.

Sonzogni, W.C., Uttormark, P.D. and G.F. Lee (1976). "A Phosphorus Residence Time Model: Theory and Application" Water Res., 10, p. 429-435.

Stumm, W. and Morgan, J.J. (1970). Aquatic Chemistry, Wiley Interscience, New York, 583 p.

Sydor, M. (1975). "Red Clay Turbidity and Its Transport in Western Lake Superior", Report of the Space Science Center, University of Minnesota, Duluth.

U.S. Army Corps of Engineers, (1971). "Great Lakes Region Inventory Report National Shoreline Study", North Central Division, Chicago, Illinois 188 p.

U.S. Army Corps of Engineers (1975). " Lake Erie Wastewater Management Study Preliminary Feasibility Report", Vol. I, Buffalo District, 172 p.

U.S. Army Corps of Engineers (1976). "Great Lakes Shoreland Damage Study", Summary Report plus Eight Appendices, North Central Division, Chicago, Illinois.

U.S. Environmental Protection Agency (1971). "Inter-Laboratory Provision Test: An Eight-Laboratory Evaluation of the Provisional Algal Assay Procedure Bottle Test", National Eutrophication Research Program, Corvalles, Oregon, 70 p.

U.S. Environmental Protection Agency (1974). "Methods for Chemical Analysis of Water and Wastes" Methods Development and Quality Assurance Research Laboratory, National Environmental Research Center, Cincinnati, Ohio.

Upper Lakes Reference Group (1976). "The Waters of Lake Huron and Lake Superior"Volume I, Summary and Recommendations, Report to the International Joint Commission, Upper Lakes Reference Group Study, Windsor, Ontario, 236 p.

Veatch, J.O. (1953). Soils and Land of Michigan, Michigan State University Press, East Lansing, 241 p.

Wilding, L. and Logan, T. (1976). "Maumee River Watershed Study" Pollution from Land Use Activities Reference Group, International Joint Commission, unpublished data.

Williams, J.D.H., Jaquet, J-M. and R.L. Thomas (1976). "Forms of Phosphorus in Surficial Sediments of Lake Erie", J. Fish. Res. Bd. Canada, 33, 3, p. 413-429.

Williams, J.D.H. and Mayer, T. (1972). "Effects of Sediment Diagenesis and Regeneration of Phosphorus with Special Reference to Lakes Erie and Ontario", in H.E. Allen and J.R. Kramer (ed.), Nutrients in Natural Waters, Wiley-Interscience, New York, p. 281-315.

Williams, J.D.H., Syers, J.K., Shukla, S.S., Harris, R.F. and D.E. Armstrong (1971). "Levels of Inorganic and Total Phosphorus in Lake Sediments as Related to Other Sediment Parameters", Envir. Sci. and Tech., 5, p. 1113-1120.

APPENDIX

The samples shown in this Appendix were collected by local organizations under contract to the U.S. Army Corps of Engineers with the assistance of soil scientists from the U.S. Soil Conservation Service. Samples, were analyzed by the U.S. Environmental Protection Agency Region V Laboratory in Chicago, Illinois.

A.

U.S. SHORELINE SOIL SAMPLE DATA

ST. LOUIS COUNTY, MINNESOTA

PROFILE NUMBER: 1
LOCATION: Stoney Point, West of drive, SW 1/4, Section 2, T51N., R12W.
SHORE TYPE: Non-erodible low bluff (despite non-erodible designation by Corps of Engineers, bluff found to be erodible by collectors)
DATE OF COLLECTION: June 4, 1975
COLLECTORS: Minnesota Dept. of Natural Resources and Arrowhead Regional Development Commission
SUPPLEMENTAL INFORMATION: About 150 feet east of profile, bedrock is about 5 feet above lake level; a complete description of the soil characteristics for all depths is available; only descriptions for the depths sampled are given here.

Sample Depth	Sample Number	Sample Description
2-5"(5.1-12.7 cm)	SL-1-1	A2 horizon; dark reddish gray (5YR 5/2) silt loam, weak fine platy structure; friable; abundant fine and very fine roots; clear wavy boundary.
10-25"(25.4-63.5 cm)	SL-1-2	B2T horizon; reddish brown (2.5YR 4/4) clay; lacustrine; strong fine angular and subangular blocky structure, very plastic; clear wavy boundary.
25-40"(63.5-101.6 cm)	SL-1-3	C1 ca horizon; reddish brown (2.5 YR 4/4) clay; lacustrine; strong fine angular and subangular blocky structure, very plastic; many 1 to 2 cm soft carbonate concretions; strong effervescence with HCl; gradual smooth boundary.
56-252"(142.2-640.1 cm)	SL-1-4	IIC3 horizon; reddish brown (5YR 4/4 to 2.5YR 4/4) loam glacial till; massive in place, medium angular and subangular blocky structure when displaced; about 10 percent coarse fragments mostly 0.2 to 1 cm; slight effervescence with HCl; abrupt smooth boundary.
252-432"+(640.1-1097.2+ cm)	SL-1-5	IIIC4 horizon; dark reddish brown (5YR 3/2) fine sandy glacial till; massive in place; strong coarse platy structure when displaced; about 20% coarse fragments mostly 0.2 to 8 cm; slight effervescence with HCl.

PROFILE NUMBER: 2
LOCATION: Duluth Tent and Trailer Park; SW 1/4, Section 19, T41N., R12W.
SHORE TYPE: Non-erodible low bluff (despite non-erodible classification by Corps of Engineers, the collectors found that this area was erodible)
DATE OF COLLECTION: June 5, 1975
COLLECTORS: Minnesota Dept. of Natural Resources and Arrowhead Regional Development Commission
SUPPLEMENT INFORMATION: No evidence of bedrock at this site.

Sample Depth	Sample Number	Sample Description
0-3"(0-7.6 cm)	SL-2-1	A1 and A2 horizon; A1 horizon a very dark gray (10YR 3/1) silt loam with a strong very fine subangular blocky and granular structure, abundant fine and very fine roots; abrupt wavy boundary and friable; A2 horizon a dark grayish brown (5YR 5/2) silt loam with weak fine platy structure, abundant fine and very fine roots, clear wavy boundary and friable.
6-24"(15.2-61.0 cm)	SL-2-2	B2T horizon; reddish brown (2.5YR 4/4) clay lacustrine; strong very fine subangular blocky structure; very plastic; clear wavy boundary.
24-114"(61.0-289.6 cm)	SL-2-3	C1 horizon; reddish brown (2.5YR 4/4) clay lacustrine; strong coarse angular blocky structure; few slickensides; very plastic; strong effervescence with HCl; carbonates in form of hard concretions; abrupt smooth boundary.
114-150"(289.6-381.0 cm)	SL-2-4	IIC2 horizon; dark reddish brown (5YR 3/2) loam with few 5 to 20 mm strata of dark reddish gray fine and very fine sandy loam; probably local sediments; well sorted; less than 1% coarse fragments; coarse angular blocky structure; hard; moderate effervescence with HCl, abrupt smooth boundary.
150-234"+(381.0-594.4+ cm)	SL-2-5	IIIC3 horizpn; dark reddish brown (5YR 3/2) fine sandy loam glacial till; massive in place parting to strong coarse platy structure when displaced; about 15 to 20% coarse fragments mostly 0.2 to 80 cm. mainly dark colored igneous rocks; slight effervescence with HCl.

PROFILE NUMBER: 3
LOCATION: Leif Erikson Park; SE 1/4, Section 23, T50N., R14W.
SHORE TYPE: Erodible low bluff
DATE OF COLLECTION: June 6, 1975
COLLECTORS: Minnesota Dept. of Natural Resources and Arrowhead Regional Development Commission
SUPPLEMENTAL INFORMATION: A1 horizon described but not sampled; bedrock (lava flow) found at depths greater than 360" (9.14 m).

Sample Depth	Sample Number	Sample Description
2-16"(5.1-40.6 cm)	SL-3-1	Bhir horizon; reddish brown (5YR 4/3) silt loam to very fine sandy loam; weak very fine subangular blocky structure; about 2 to 10% coarse fragments ranging from 1 to 4 cm; very friable; abrupt smooth boundary.
16-30"(40.6-76.2 cm)	SL-3-2	IIB2T horizon; reddish brown (2.5YR 4/4) clay lacustrine; strong fine angular and subangular blocky structure; very plastic; clay films are not distinct on ped faces; ped surfaces are glossy; abrupt irregular boundary.
30-108"(76.2-274.3 cm)	SL-3-3	IIC1ca horizon; reddish brown (2.5YR 4/4) clay lacustrine; strong fine to coarse angular and subangular blocky structure; very plastic; strong effervescence with HCl; carbonates are in form of threads and concretions about 1 to 2 percent coarse fragments ranging from 0.5 to 2 cm in the lower 36 inches; abrupt smooth boundary.
108-198"(274.3-502.9 cm)	SL-3-4	IIIC2 horizon; dark reddish brown to reddish brown (5YR 3/3 to 4/3) loam glacial till; massive in place parting coarse angular blocky structure when displaced; about 10 to 15 percent coarse fragments ranging from 0.2 to 15 cm mostly dark color igneous rocks; slight effervescence with HCl; abrupt smooth boundary.
198-360"(502.9-914.4 cm)	SL-3-5	IVC3 horizon; dark gray to dark reddish brown (5YR 3/1 to 3/2) gravelly fine sandy loam glacial till, massive in place parting to medium coarse platy structure when displaced; about 15 to 20% coarse fragments ranging from 0.2 to 2.5 cm mostly dark color igneous rocks; dense in place; friable when displaced; slight effervescence with HCl.

PROFILE NUMBER: 4
LOCATION: Lake Avenue and 12th Street South
SHORE TYPE: Erodible low plain
DATE OF COLLECTION: June, 1975
COLLECTORS: Minnesota Dept. of Natural Resources and Arrowhead Regional Development Commission
SUPPLEMENTAL INFORMATION:

Sample Depth	Sample Number	Sample Description
3'(0.9 m)	SL-4-1	Light brown (7.5YR 4/4) coarse sand; single grained, loose; some fine bedding.
7'(2.1 m)	SL-4-2	Light brown (u.5YR 4/4) coarse sand; single grained, loose; some fine bedding.

PROFILE NUMBER: 5
LOCATION: South Park Point; T.49N., R.13W
SHORE TYPE: Erodible low plain
DATE OF COLLECTION: June 3, 1975
COLLECTORS: Minnesota Dept. of Natural Resources and Arrowhead Regional Development Commission
SUPPLEMENTAL INFORMATION:

Sample Depth	Sample Number	Sample Description
2'(0.6 m)	SL-5-1	Light brown (7.5YR 6/4) coarse sand; single grained; loose; some fine bedding.
8'(2.4 m)	SL-5-2	Same as SL-5-1.

PROFILE NUMBER: 6
LOCATION: 21st Avenue West
SHORE TYPE:
DATE OF COLLECTION: June 9, 1975
COLLECTORS: Minnesota Dept. of Natural Resources and Arrowhead Regional Development Commission
SUPPLEMENTAL INFORMATION: Materials at this site could be dredged from the harbor, since the entire area appeared to the collectors to be fill material. Only about 0.9 m could be penetrated with a hand auger as concrete boulders, wood, etc. were encountered. The first 10 inches of the profile was described as to soil characteristics, but no sample was taken.

PROFILE NUMBER: 6(continued)

Sample Depth	Sample Number	Sample Description
10-24"(25.4-61.0 cm)	SL-6-1	Dark brown (10YR 3/3) fine loamy sand; weak medium subangular blocky structure; very friable.
24-36"(61.0-91.4 cm)	SL-6-2	Very dark grayish brown (10YR 3/2) fine loamy sand; weak medium subangular blocky structure.

PROFILE NUMBER: 7
LOCATION: 81st Avenue West, Duluth; NE 1/4, NE 1/4, Section 24, T49N, R15W
SHORE TYPE:
DATE OF COLLECTION: June 6, 1975
COLLECTORS: Minnesota Dept. of Natural Resources and Arrowhead Regional Development Commission
SUPPLEMENTAL INFORMATION: Sample site was reported to have been disturbed by the collectors. The first 80 inches (203.2 cm) were described as to soil characteristics, although samples were not taken from all depths.

Sample Depth	Sample Number	Sample Description
2-34"(5.1-61.4 cm)	SL-7-1	Weak red (10YR 4/4) clay; strong moderate subangular blocky structure; few hard carbonate concretions ranging from 10 to 20 mm across; few 5 to 10" thick seams of sand; slight effervescence with HCl.
44-80"+(111.8-203.2+ cm)	SL-7-2	Mixed materials consisting predominantly of reddish brown clay with some dark reddish gray silt loam surface and subsurface soil.

ST. LOUIS PROFILE 1 (mg/kg dry weight)*

Sample Depth (Number)	2-5"(SL-1-1)		10-25"(SL-1-2)		25-40"(SL-1-3)		56-252"(SL-1-4)		252-430"(SL-1-5)		
Parameter	Total	Extr.	Total	Extr.	Total	Extr.	Total	Extr.	Total	Extr.	Total Extr.
Total Phosphorus	210	31	320	200	200	190	330	360	550	310	
Orthophosphate-P		31		198		103		340		310	
Total Kjeldahl Nitrogen	720	41	430	41	58	10	60	48	K36	29	
Nitrate/Nitrite-N		26		27		6		7		8	
Ammonia-N		20		25		K9		15		17	
Total Organic Carbon	8500	400	4600	300	2500	200	3400	700	400	100	
Calcium	1580	1440	5320	4150	54000	46700	32000	30600	13200	8700	
Magnesium	3160	249	10500	1220	19600	5600	14000	5240	6870	1030	
Sodium	K250	23.2	K250	61.4	890	48.1	560	68.8	659	96.7	
Iron	10920	90.3	25100	360	24000	K2	20300	165	21200	677	
Manganese	259	8.4	585	11.9	630	92.7	490	127	390	118	
Aluminum	5670	521	21100	1240	19800	4.0	10900	543	9300	755	
Titanium	240	1.8	630	6.8	1220	K1	483	K1	1200	1.6	
% Total Solids (105°C)	84.6		80.8		82.4		82.8		92.0		
Specific Gravity (20°C)	2.67		2.55		2.60		2.28		2.65		
Boron	K150	K2	K150	2.0	K150	3.8	K150	3.7	K150	2.4	
Barium	51	34.3	K50	116	180	27.5	120	55.6	74	11.9	
Cadmium	K1	K1	K1	1.1	1	K1	K1	1.1	K1	1.0	
Cobalt	K250	K2	K250	K2	K250	K2	K250	K2	K250	3.0	
Chromium	K50	K1	K50	K1	K50	K1	K50	K1	K50	0.3	
Copper	11	K1	K10	3.9	41	K1	36	3.7	36	12.7	
Molybdenum	K300	K5	K300	K5	K300	K5	K300	K5	K300	2.4	
Lead	9	K10	15	K10	24	K10	16	K10	10	K3	
Tin	K500	K10	K500	K10	K500	K10	K500	K10	K500	K3	
Vanadium	K100	K10	140	K10	207	K10	167	K10	170	K5	
Yttrium	K20	K1	K20	4.0	K20	K1	K20	5.4	K20	4.4	
Zinc	K50	3.4	56	5.3	68	K1	54	4.6	61	18.7	

*K indicates "less than".

ST. LOUIS PROFILE 2 (mg/kg dry weight)*

Sample Depth (Number)	0-3"(SL-2-1)		6-24"(SL-2-2)		24-114"(SL-2-3)		114-150"(SL-2-4)		150-234"(SL-2-5)			
Parameter	Total	Extr.	Total	Extr.	Total	Extr.	Total	Extr.	Total	Extr.	Total	Extr.
Total Phosphorus	430	95	490	380	470	410	580	510	500	340		
Orthophosphate-P		90		380		410		540		320		
Total Kjeldahl Nitrogen	2400	31	470	19	340	17	220	17	99	12		
Nitrate/Nitrite-N		34		K6		K6		K6		8		
Ammonia-N		12		K9		10		K9		10		
Total Organic Carbon	29000	500	3000	200	1100	100	1500	K100	500	K100		
Calcium	5460	4430	6840	8350	36300	37100	16500	14500	146000	30100		
Magnesium	6260	663	11500	1770	14900	4090	8800	1870	6800	1810		
Sodium	K250	26.7	490	50.6	530	58.2	500	48.2	620	39.8		
Iron	17700	80.4	27200	575	24600	824	22300	955	22300	2580		
Manganese	420	52.5	550	64.7	540	154	460	164	410	464		
Aluminum	10500	599	18800	1310	15800	979	10800	478	9430	358		
Titanium	490	2.1	550	7.0	700	1.6	870	2.9	1090	1.4		
% Total Solids (105°C)	73.4		86.2		77.6		89.5		90.3			
Specific Gravity (20°C)	2.04		2.51		2.07		2.20		2.76			
Boron	K150	2.5	K150	2.1	K150	3.4	K150	3.1	K150	4.4		
Barium	104	62.1	191	109	173	84.7	109	20.9	66	12.0		
Cadmium	K1	1.1	K1	K1	K1	1.1	K1	1.2	K1	1.6		
Cobalt	K250	K2	K250	2.9	K250	2.8	K250	4.3	K250	8.3		
Chromium	K50	K1	K50	1.0	K50	1.5	K50	K1	K50	1.0		
Copper	24	1.4	49	6.2	43	5.1	38	16.8	41	12.5		
Molybdenum	K300	K5	K300	K5	K300	K5	K300	K5	K300	K2		
Lead	28	K10	16	K10	18	K10	11	K10	10	K3		
Tin	K500	K10	K500	K10	K500	K10	K500	K10	K500	K3		
Vanadium	130	K10	180	K10	210	K10	173	K10	180	K5		
Yttrium	K20	K1	K20	6.6	K20	7.0	K20	5.7	K20	7.6		
Zinc	63	7.5	72	7.0	74	7.0	66	10.7	63	5.6		

*K indicates "less than".

ST. LOUIS PROFILE 3 (mg/kg dry weight)*

Sample Depth (Number)	2-16"(SL-3-1)		16-30"(SL-3-2)		30-108"(SL-3-3)		108-198"(SL-3-4)		198-234"(SL-3-5)			
Parameter	Total	Extr.	Total	Extr.	Total	Extr.	Total	Extr.	Total	Extr.	Total	Extr.
Total Phosphorus	470	29	230	340	430	370	520	450	490	400		
Orthophosphate-P		26		360		370		460		370		
Total Kjeldahl Nitrogen	890	20	220	23	240	19	160	11	140	14		
Nitrate/Nitrite-N		16		K6		K6		K6		7		
Ammonia-N		10		12		9		9		K9		
Total Organic Carbon	11000	200	2700	200	1400	100	400	K100	600	K100		
Calcium	4300	2950	3580	4040	25400	24700	15300	12900	18000	5120		
Magnesium	4670	359	5860	1260	14300	4260	9000	1710	11700	652		
Sodium	K250	25.5	K250	41.2	564	59.8	530	45.9	720	68		
Iron	19500	162	19500	310	27300	173	25000	273	41400	433		
Manganese	608	42.0	446	29.6	448	152	490	129	636	54.9		
Aluminum	9830	500	10500	877	17350	680	11300	664	15400	919		
Titanium	930	2.3	302	3.7	825	K1	770	1.4	1190	1.3		
% Total Solids (105°C)	85.3		83.8		79.4		84.4		88.1			
Specific Gravity (20°C)	2.45		2.63		2.51		1.79		2.62			
Boron	K150	K2	K150	2.2	K150	2.7	K150	K2	K150	K2		
Barium	90	38.3	114	92.5	168	78.1	103	43.4	105	11.1		
Cadmium	K1	K1	K1	K1	K1	K1	K1	K1	K1	K1		
Cobalt	K250	K2	K250	K2	K250	2.0	K250	2.0	K250	K2		
Chromium	K50	K1	K50	K1	K50	K1	K50	K1	K50	K1		
Copper	30	1.8	34	5.1	48	4.9	52	11.1	56	13.8		
Molybdenum	K300	K5	K300	K5	K300	K5	K300	K5	K300	K5		
Lead	15	K10	9	K10	17	K10	12	K10	14	K10		
Tin	K500	K10	K500	K10	K500	K10	K500	K10	K500	K10		
Vanadium	160	K10	163	K10	196	K10	170	K10	K100	K10		
Yttrium	K20	K1	K20	4.4	K20	4.7	K20	5.0	K20	4.3		
Zinc	57	3.5	K50	5.5	80	6.9	71	5.7	73	5.3		

*K indicates "less than".

ST. LOUIS PROFILE 4 (mg/kg dry weight)*

Sample Depth (Number)	3'(SL-4-1)		7'(SL-4-2)									
Parameter	Total	Extr.	Total	Extr.	Total	Extr.	Total	Extr.	Total	Extr.	Total	Extr.
Total Phosphorus	130	120	120	90								
Orthophosphate-P		105		89								
Total Kjeldahl Nitrogen	52	13	19	14								
Nitrate/Nitrite-N		K6		8								
Ammonia-N		K9		9								
Total Organic Carbon	400	100	K300	K100								
Calcium	575	434	850	350								
Magnesium	514	35.4	830	35.4								
Sodium	31	9.4	K250	18.7								
Iron	3500	73.7	5500	62.1								
Manganese	31	2.8	290	5.0								
Aluminum	854	96	1330	88								
Titanium	101	0.6	290	K1								
% Total Solids (105°C)	96.7		83.9									
Specific Gravity (20°C)	2.60		2.70									
Boron	K15	K1	K150	K2								
Barium	6	2.7	K50	3.6								
Cadmium	K1	0.6	K1	K1								
Cobalt	K25	K1	K250	K2								
Chromium	K5	K0.3	K50	K1								
Copper	2	0.5	K10	K1								
Molybdenum	K30	K2	K300	K5								
Lead	K5	K3	K5	K10								
Tin	K50	K3	K500	K10								
Vanadium	K10	K5	K100	K10								
Yttrium	K2	0.4	K20	K1								
Zinc	8	2.4	K50	2.9								

*K indicates "less than".

ST. LOUIS PROFILE 5 (mg/kg dry weight)*

Sample Depth (Number)	2'(SL-5-1)		8'(SL-5-2)									
Parameter	Total	Extr.	Total	Extr.	Total	Extr.	Total	Extr.	Total	Extr.	Total	Extr.
Total Phosphorus	170	100	100	53								
Orthophosphate-P		100		52								
Total Kjeldahl Nitrogen	38	11	45	13								
Nitrate/Nitrite-N		6		K6								
Ammonia-N		K9		K9								
Total Organic Carbon	K300	K100	K300	K100								
Calcium	945	303	1300	296								
Magnesium	940	25.6	980	78.3								
Sodium	K250	6.6	K250	6.1								
Iron	30800	67.1	10800	49.6								
Manganese	154	7.0	167	6.8								
Aluminum	1500	53	1600	58								
Titanium	1060	0.6	339	0.5								
% Total Solids (105°C)	96.8		90.0									
Specific Gravity (20°C)	2.70		2.65									
Boron	K150	K1	K150	K1								
Barium	K50	3.9	K50	4.1								
Cadmium	K1	K0.5	K1	K0.5								
Cobalt	K250	K1	K250	K1								
Chromium	K50	K0.3	490	K0.3								
Copper	K10	0.3	K10	K0.3								
Molybdenum	K300	K2	K300	K2								
Lead	K5	K3	K5	K3								
Tin	K500	K3	K500	K3								
Vanadium	106	K5	K100	K5								
Yttrium	K20	0.8	K20	0.5								
Zinc	K50	2.5	199	2.7								

*K indicates "less than".

ST. LOUIS PROFILE 6 (mg/kg dry weight)*

Sample Depth (Number)	10-24"(SL-6-1)		24-36"(SL-6-2)									
Parameter	Total	Extr.	Total	Extr.	Total	Extr.	Total	Extr.	Total	Extr.	Total	Extr.
Total Phosphorus	360	230	300	190								
Orthophosphate-P		229		192								
Total Kjeldahl Nitrogen	520	25	480	20								
Nitrate/Nitrite-N		17		11								
Ammonia-N		14		12								
Total Organic Carbon	10000	200	12000	200								
Calcium	6500	3120	3960	3310								
Magnesium	5050	1030	3440	1010								
Sodium	290	22.6	K250	25.0								
Iron	17500	424	15500	549								
Manganese	230	42.7	171	48.6								
Aluminum	6090	382	4620	342								
Titanium	695	3.6	650	4.6								
% Total Solids (105°C)	86.5		82.9									
Specific Gravity (20°C)	2.54		2.56									
Boron	K150	2.5	K150	2.4								
Barium	K50	16.6	K50	16.9								
Cadmium	K1	K1	K1	1.1								
Cobalt	K250	2.4	K250	2.5								
Chromium	K50	K1	K50	K1								
Copper	18	5.2	15	5.6								
Molybdenum	K300	K5	K300	K5								
Lead	20	K10	15	K10								
Tin	K500	K10	K500	K10								
Vanadium	K100	K10	K100	K10								
Yttrium	K20	2.2	K20	2.1								
Zinc	K50	8.4	K50	9.8								

*K indicates "less than".

ST. LOUIS PROFILE 7 (mg/kg dry weight)*

Sample Depth (Number)	2-34"(SL-7-1)		44-80"(SL-7-2)									
Parameter	Total	Extr.	Total	Extr.	Total	Extr.	Total	Extr.	Total	Extr.	Total	Extr.
Total Phosphorus	410	380	560	150								
Orthophosphate-P		390		147								
Total Kjeldahl Nitrogen	330	14	360	25								
Nitrate/Nitrite-N		K6		8								
Ammonia-N		10		9								
Total Organic Carbon	2200	K100	2300	300								
Calcium	21700	25200	6600	3770								
Magnesium	21400	3610	13500	1280								
Sodium	740	60.9	690	81.5								
Iron	49900	201	41200	259								
Manganese	673	158	112	71.0								
Aluminum	29800	934	22600	1020								
Titanium	700	K1	1100	3.3								
% Total Solids (105°C)	75.3		76.7									
Specific Gravity (20°C)	2.76		2.74									
Boron	K150	3.0	K150	2.0								
Barium	290	139	210	92								
Cadmium	K1	K1	K1	K1								
Cobalt	K250	K2	K250	K2								
Chromium	K55	K1	52	K1								
Copper	55	4.5	45	2.8								
Molybdenum	K300	K5	K300	K5								
Lead	21	K10	15	K10								
Tin	K500	K10	K500	K10								
Vanadium	100	K10	K100	K10								
Yttrium	K20	6.4	K20	2.0								
Zinc	89	4.1	70	6.8								

*K indicates "less than".

DOUGLAS COUNTY, WISCONSIN

PROFILE NUMBER: 1
LOCATION: At the mouth of the Brule River (east side near parking lot) in Section 10 T.49N., R10W.
SHORE TYPE: Erodible high bluff
DATE OF COLLECTION: May 28, 1975
COLLECTORS: University of Wisconsin-Superior and Wisconsin DNR
SUPPLEMENTAL INFORMATION:

Sample Depth	Sample Number	Sample Description
0-3"(0-7.6 cm)	D-1-1	A horizon.
8'(2.4 m)	D-1-2	Composite clay sample.

PROFILE NUMBER: 2
LOCATION: At terminus of road and shoreline in Section 18, T. 49N., R. 10W.
SHORE TYPE: Erodible high bluff
DATE OF COLLECTION: May 28, 1975
COLLECTORS: University of Wisconsin-Superior
SUPPLEMENTAL INFORMATION: Bluff edge approximately 50 feet (15.2 m) above lake level. Narrow beach at toe of bluff, approximately 2 feet (0.6 m) wide with a heavy concentration of magnetite-illmenite.

Sample Depth	Sample Number	Sample Description
0"	D-2-1	No A horizon; clay extends to surface.
12'(3.7 m)	D-2-2	Clay at surface; sample site approximately 12 feet (3.6 m) below bluff edge.

PROFILE NUMBER: 3
LOCATION: At the terminus of Peterson Road and the lakeshore in Section 28, T. 49N., R. 11W.
DATE OF COLLECTION: May 28, 1975
COLLECTORS: University of Wisconsin-Superior
SUPPLEMENTAL INFORMATION: Sample at base of bluff.
SHORE TYPE: Erodible high bluff.

Sample Depth	Sample Number	Sample Description
0"	D-3-1	A horizon; black soil.
10'(3.0 m)	D-3-2	Clay, in place.

PROFILE NUMBER: 4
LOCATION: East of road terminus in Section 35, T. 49N., R. 13W.
SHORE TYPE: Erodible high bluff
DATE OF COLLECTION: May 28, 1975
COLLECTORS: University of Wisconsin-Superior
SUPPLEMENTAL INFORMATION: Sand beach approximately 9 feet (2.7 m) wide at toe of bluff.

Sample Depth	Sample Number	Sample Description
0"	D-4-1	No soil horizons; clay extends to surface.
10'(3.0 m)	D-4-2	Clay.

DOUGLAS PROFILE 1 (mg/kg dry weight)*

Sample Depth (Number)	0-3"(D-1-1)		8'(D-1-2)									
Parameter	Total	Extr.	Total	Extr.	Total	Extr.	Total	Extr.	Total	Extr.	Total	Extr.
Total Phosphorus	380	26	420	410								
Orthophosphate-P		25		420								
Total Kjeldahl Nitrogen	2500	30	180	43								
Nitrate/Nitrite-N		28		K6								
Ammonia-N		K9		24								
Total Organic Carbon	22000	1000	2600	K100								
Calcium	2550	2370	24000	23800								
Magnesium	4720	605	19100	4470								
Sodium	K250	47.3	610	154								
Iron	21100	110	42500	240								
Manganese	406	10.6	577	123								
Aluminum	9560	474	23100	772								
Titanium	253	2.5	530	K1								
% Total Solids (105°C)	81.2		67.4									
Specific Gravity (20°C)	2.18		2.73									
Boron	K150	K2	K150	2.3								
Barium	115	65.8	260	128								
Cadmium	K1	K1	K1	K1								
Cobalt	K250	K2	K250	K2								
Chromium	K50	K1	K50	K1								
Copper	17	1.8	46	4.1								
Molybdenum	K300	K5	K300	K5								
Lead	34	K10	21	K10								
Tin	K500	K10	K500	K10								
Vanadium	K100	K10	K100	K10								
Yttrium	K20	K1	K20	5.6								
Zinc	K50	9.2	74	5.2								

*K indicates "less than".

DOUGLAS PROFILE 2 (mg/kg dry weight)*

Sample Depth (Number)	0"(D-2-1)		12'(D-2-2)									
Parameter	Total	Extr.	Total	Extr.	Total	Extr.	Total	Extr.	Total	Extr.	Total	Extr.
Total Phosphorus	420	12	400	360								
Orthophosphate-P		11		370								
Total Kjeldahl Nitrogen	530	22	140	18								
Nitrate/Nitrite-N		10		K6								
Ammonia-N		K9		14								
Total Organic Carbon	4900	300	500	K100								
Calcium	4400	3340	26300	19600								
Magnesium	10900	1780	18300	4530								
Sodium	K250	27.5	610	71.6								
Iron	34900	296	37700	229								
Manganese	520	21.1	585	151								
Aluminum	19000	1030	1940	600								
Titanium	270	5.0	580	1.3								
% Total Solids (105°C)	77.4		72.6									
Specific Gravity (20°C)	2.73		2.62									
Boron	K150	K2	K150	4.0								
Barium	210	105	210	114								
Cadmium	K1	1.1	K1	1.2								
Cobalt	K250	2.1	K250	K2								
Chromium	K50	K1	K50	K1								
Copper	37	3.9	42	3.6								
Molybdenum	K300	K5	K300	K5								
Lead	15	K10	19	K10								
Tin	K500	K10	K500	12.2								
Vanadium	K100	K10	K100	K10								
Yttrium	K20	K1	K20	5.2								
Zinc	K50	4.1	68	5.8								

*K indicates "less than".

DOUGLAS PROFILE 3 (mg/kg dry weight)*

Sample Depth (Number)	0"(D-3-1)		10'(D-3-2)									
Parameter	Total	Extr.	Total	Extr.	Total	Extr.	Total	Extr.	Total	Extr.	Total	Extr.
Total Phosphorus	360	12	460	340								
Orthophosphate-P		10		330								
Total Kjeldahl Nitrogen	2600	60	160	K10								
Nitrate/Nitrite-N		12		K6								
Ammonia-N		36		K9								
Total Organic Carbon	28000	600	2300	K100								
Calcium	3200	2820	45100	31200								
Magnesium	6060	722	20100	5390								
Sodium	K250	15.0	700	86								
Iron	29000	161	36200	58.6								
Manganese	453	16.2	649	109								
Aluminum	16900	1330	20400	387								
Titanium	210	2.1	888	K1								
% Total Solids (105°C)	71.0		77.7									
Specific Gravity (20°C)	2.01		2.55									
Boron	K150	K2	K150	4.2								
Barium	K50	103	217	76								
Cadmium	K1	K1	K1	K1								
Cobalt	K250	K2	K250	K2								
Chromium	K50	K1	K50	1.7								
Copper	K10	K1	47	1.2								
Molybdenum	K300	K5	K300	5.0								
Lead	20	K10	22	K10								
Tin	K500	K10	K500	22.5								
Vanadium	K100	K10	K100	K10								
Yttrium	K20	K1	K20	5.2								
Zinc	70	6.3	68	2.6								

*K indicates "less than".

DOUGLAS PROFILE 4 (mg/kg dry weight)*

Sample Depth (Number)	0"(D-4-1)		10'(D-4-2)									
Parameter	Total	Extr.	Total	Extr.	Total	Extr.	Total	Extr.	Total	Extr.	Total	Extr.
Total Phosphorus	240	140	460	440								
Orthophosphate-P		140		440								
Total Kjeldahl Nitrogen	410	27	500	70								
Nitrate/Nitrite-N		K6		K6								
Ammonia-N		14		18								
Total Organic Carbon	4000	300	2800	K100								
Calcium	3270	3290	36300	32400								
Magnesium	11200	1770	23900	6110								
Sodium	K250	64.1	940	192								
Iron	38300	164	45900	221								
Manganese	450	14.1	720	164								
Aluminum	21500	919	26800	754								
Titanium	260	4.8	715	K1								
% Total Solids (105°C)	82.7		70.9									
Specific Gravity (20°C)	2.73		2.63									
Boron	K150	K2	K150	3.0								
Barium	197	105	74	95								
Cadmium	K1	K1	K1	K1								
Cobalt	K250	K2	K250	2.0								
Chromium	K50	K1	55	1.4								
Copper	40	2.3	54	5.0								
Molybdenum	K300	K5	K300	K5								
Lead	14	K10	24	K10								
Tin	K500	K10	K500	K10								
Vanadium	K100	K10	K100	K10								
Yttrium	K20	2.1	K20	6.6								
Zinc	53	4.7	84	14.0								

*K indicates "less than".

PROFILE NUMBER: 1
LOCATION: At Whitefish Point; approximately NW 1/4, SE 1/4, Sec. 32, T51N, R5W.
SHORE TYPE: Non-erodible low bluff (Despite this classification assigned by the U.S. Army Corps of Engineers, there is evidence that this bluff erodes.)
DATE OF COLLECTION: June 23-25, 1975
COLLECTORS: University of Michigan Coastal Zone Laboratory
SUPPLEMENTAL INFORMATION: Water table at approximately 200 cm. Sample 033-4-4 taken from face of bluff.

Sample Depth	Sample Number	Sample Description
0-27"(0-68.6 cm)	033-4-1	C1 horizon; white (10YR 8/2) sand; single grained; loose; high proportion of dark minerals; strongly acid; abrupt smooth boundary.
27-35"(68.6-88.9 cm)	033-4-2	C2 horizon; very pale brown (10YR 7/3) sand; single grained; loose; strongly acid; abrupt smooth boundary.
35-60"(88.9-152.4 cm)	033-4-3	C3 horizon; white (10 YR 8/1 & 8/2) sand; single grained; loose; high proportion of dark minerals; strongly acid.
0-60"(0-152.4 cm)	033-4-4	C3 horizon; stratified white (10YR 8/2 & 8/1) and very pale brown (10YR 7/3) sand; single grained; loose; varying proportions of dark minerals in different strata; strongly acid.

PROFILE NUMBER: 2
LOCATION: At Paradise at end of M-123 Extended (behind Curly's Motel); SE 1/4, SE 1/4, Section 22, T49N, R6W.
SHORE TYPE: Erodible low bluff
DATE OF COLLECTION: June 23-25, 1975
COLLECTORS: University of Michigan Coastal Zone Laboratory
SUPPLEMENTAL INFORMATION: Water table below 200 cm. Samples 033-3-7 and 033-3-8 taken from face of bluff.

Sample Depth	Sample Number	Sample Description
0-2"(0-5.1 cm)	033-3-1	A1 horizon; black (10YR 2/1) sand; very weak fine granular structure; very friable; very strongly acid; abrupt smooth boundary.
2-12"(5.1-30.5 cm)	033-3-2	A21 horizon; light gray (10 YR 7/2) sand; single grained; loose; very strongly acid; gradual wavy boundary.

PROFILE NUMBER: 2(continued)

Sample Depth	Sample Number	Sample Description
12-36"(30.5-91.4 cm)	033-3-3	A22 horizon; light yellowish brown (10YR 6/4) sand; single grained; loose; very strongly acid; gradual wavy boundary.
36-44"(91.4-111.8 cm)	033-3-4	A23 and B1 horizon; very pale brown (10YR 7/3)(A) and brown (7.5YR 5/4)(B) fine sand; single grained; loose; very strongly acid; gradual wavy boundary.
44-50"(111.8-127.0 cm)	033-3-5	B2 horizon; dark brown (7.5YR 4/4) fine sand; single grained; loose; strongly acid; abrupt wavy boundary.
50-62"(127.0-157.5 cm)	033-3-6	C1 horizon; light yellowish brown (10YR 6/4) fine sand; single grained; loose; strongly acid.
0-26"(0-66.0 cm)	033-3-7	C1 horizon; light yellowish brown (10YR 6/4) fine sand; single grained; loose; very strongly acid; gradual wavy boundary.
26-60"(66.0-152.4 cm)	033-3-8	C2 horizon; light gray (10YR 7/2) fine sand; single grained; loose; very strongly acid.

PROFILE NUMBER: 3
LOCATION: East of Paradise; on line between Section 14 and 15, T47N, R5W, at shoreline.
SHORE TYPE: Erodible low plain
DATE OF COLLECTION: June 23-25, 1975
COLLECTORS: University of Michigan Coastal Zone Laboratory
SUPPLEMENTAL INFORMATION: Water table at about 100 cm.

Sample Depth	Sample Number	Sample Description
0-28"(0-71.1 cm)	033-2-1	C1 horizon; white (10YR 8/2) coarse sand; single grained; loose; slightly acid; abrupt smooth boundary.
28-60"(71.1-152.4 cm)	033-2-2	C2 horizon; yellow (10YR 7/6) coarse sand; single grained; loose; slightly acid.

CHIPPEWA PROFILE 1 (mg/kg dry weight)*

Sample Depth (Number)	0-27"(033-4-1)		27-35"(033-4-2)		35-60"(033-4-3)		0-60"(033-4-4)					
Parameter	Total	Extr.	Total	Extr.	Total	Extr.	Total	Extr.	Total	Extr.	Total	Extr.
Total Phosphorus	77	28	49	15	140	40	92	34				
Orthophosphate-P		24		12		39		34				
Total Kjeldahl Nitrogen	K38	16	K37	10	110	16	67	11				
Nitrate/Nitrite-N		6		6		6		K6				
Ammonia-N		K9		K9		K9		K9				
Total Organic Carbon	K300	200	K300	K100	500	K100	K300	K100				
Calcium	290	106	143	74	460	154	672	148				
Magnesium	250	6.1	178	11.0	286	8.0	406	9.5				
Sodium	K250	8	K25	4	K250	8	K250	5				
Iron	8840	15.9	3500	16.4	15300	20.4	28500	19.0				
Manganese	41	0.4	16	0.3	K150	0.7	134	1.0				
Aluminum	389	19.9	297	19.1	480	25.2	680	22.2				
Titanium	220	K0.3	94	K0.3	390	K0.3	899	K0.3				
% Total Solids (105°C)	97.9		97.9		96.9		97.1					
Specific Gravity (20°C)	2.79		2.77		2.84		2.54					
Boron	K150	K1	K15	K1	K150	K1	K150	K1				
Barium	K50	0.7	K5	0.9	K50	1.2	K50	1.3				
Cadmium	K1	K0.5	K1	K0.5	K1	K0.5	K1	K0.5				
Cobalt	K250	K1	K25	K1	K250	K1	K250	K1				
Chromium	K50	K0.3	K5	K0.3	K50	K0.3	280	K0.3				
Copper	K10	K0.3	K1	K0.3	K10	K0.3	K10	K0.3				
Molybdenum	K300	K2	K30	K2	K300	K2	K300	K2				
Lead	K5	K3	K5	K3	6	K3	K5	K3				
Tin	K500	K3	K50	K3	K500	K3	K500	K3				
Vanadium	K100	K5	K10	K5	K100	K5	114	K5				
Yttrium	K10	K0.3	K2	K0.3	K20	K0.3	K20	K0.3				
Zinc	K50	2.0	K5	1.7	K50	3.5	K50	1.5				

*K indicates "less than".

CHIPPEWA PROFILE 2 (mg/kg dry weight)*

Sample Depth (Number)	0-2"(033-3-1)		2-12"(033-3-2)		12-36"(033-3-3)		36-44"(033-3-4)		44-50"(033-3-5)		50-62"(033-3-6)	
Parameter	Total	Extr.	Total	Extr.	Total	Extr.	Total	Extr.	Total	Extr.	Total	Extr.
Total Phosphorus	110	27	32	7	23	12	40	37	72	66	94	48
Orthophosphate-P		24		2		11		36		66		43
Total Kjeldahl Nitrogen	900	42	19	15	25	21	26	20	68	38	120	31
Nitrate/Nitrite-N		12		8		7		7		K6		K6
Ammonia-N		29		10		K9		K9		K9		K9
Total Organic Carbon	13000	200	800	K100	600	200	1000	600	1800	1300	1000	500
Calcium	297	425	24	58	55	41	92	30	133	56	143	101
Magnesium	51	28	20	12	57	7.1	147	5.4	262	5.6	198	6.5
Sodium	K25	19	K25	8	K25	11	K25	6	K25	10	K25	5
Iron	1015	24.2	480	5.2	468	14.8	552	68.1	880	101	695	42.7
Manganese	K15	2.1	K15	K0.3	K15	K0.3	K15	K0.3	18	1.8	K15	1.2
Aluminum	538	410	137	30.8	245	69.4	636	308	1039	483	702	275
Titanium	39	0.8	26	K0.3	48	0.6	78	3.3	87	5.4	51	2.0
% Total Solids (105°C)	89.8		97.7		96.9		96.3		91.5		96.1	
Specific Gravity (20°C)	2.49		2.80		2.63		2.67		2.69		2.77	
Boron	K15	K1	K15	K1	K15	K1	K15	K1	K15	K1	K15	K1
Barium	18	16.8	K5	K0.3	K5	0.4	K5	0.9	K5	2.6	K5	2.0
Cadmium	K1	0.7	K1	K0.5	K1	K0.5	K1	0.5	K1	0.6	K1	K0.5
Cobalt	K25	K1	K25	K1	K25	K1	K25	K1	K25	K1	K25	K1
Chromium	K5	K0.3	K5	K0.3	K5	K0.3	K5	0.4	K5	0.4	K5	K0.3
Copper	2.0	K0.3	K1	K0.3	K1	K0.3	K1	0.4	K1	0.3	K1	K0.3
Molybdenum	K30	K2	K30	K2	K30	K2	K30	K2	K30	K2	K30	K2
Lead	K5	K3	K5	K3	K5	K3	K5	K3	K5	K3	K5	K3
Tin	K50	K3	K50	K3	K50	K3	K50	K3	K50	K3	K50	K3
Vanadium	K10	K5	K10	K5	K10	K5	K10	K5	K10	K5	K10	K5
Yttrium	K2	K0.3	K2	K0.3	K2	K0.3	K2	K0.3	K2	K0.3	K2	K0.3
Zinc	8	31	K5	2.9	K5	1.6	K5	2.2	K5	2.2	K5	1.5

*K indicates "less than".

CHIPPEWA PROFILE 2 (mg/kg dry weight)* continued

Sample Depth (Number)	0-26"(033-3-7)											
Parameter	Total	Extr.	Total	Extr.	Total	Extr.	Total	Extr.	Total	Extr.	Total	Extr.
Total Phosphorus	98	59										
Orthophosphate-P		58										
Total Kjeldahl Nitrogen	59	23										
Nitrate/Nitrite-N		6										
Ammonia-N		K9										
Total Organic Carbon	1000	680										
Calcium	199	144										
Magnesium	218	9.2										
Sodium	K25	5										
Iron	684	49.3										
Manganese	K15	1.2										
Aluminum	722	295										
Titanium	57	2.6										
% Total Solids (105°C)	95.7											
Specific Gravity (20°C)	2.84											
Boron	K15	K1										
Barium	K5	1.3										
Cadmium	K1	K0.5										
Cobalt	K25	K1										
Chromium	K5	K0.3										
Copper	K1	K0.3										
Molybdenum	K30	K2										
Lead	K5	K3										
Tin	K50	K3										
Vanadium	K10	K5										
Yttrium	K2	K0.3										
Zinc	K5	1.1										

*K indicates "less than".

CHIPPEWA PROFILE 3 (mg/kg dry weight)*

Sample Depth (Number)	0-28"(033-2-1)		28-60"(033-2-2)									
Parameter	Total	Extr.	Total	Extr.	Total	Extr.	Total	Extr.	Total	Extr.	Total	Extr.
Total Phosphorus	18	11	45	16								
Orthophosphate-P		11		15								
Total Kjeldahl Nitrogen	K35	12	23	11								
Nitrate/Nitrite-N		7		K6								
Ammonia-N		9		K9								
Total Organic Carbon	500	K100	600	200								
Calcium	275	91	211	135								
Magnesium	174	9.3	87	9.4								
Sodium	24	5	K25	10								
Iron	1550	9.0	1280	31.4								
Manganese	18	2.0	K15	0.4								
Aluminum	364	13.3	304	79.5								
Titanium	62	K0.3	26	K0.3								
% Total Solids (105°C)	98.6		96.1									
Specific Gravity (20°C)	2.63		2.71									
Boron	K15	K1	K15	K1								
Barium	K5	0.8	K5	1.0								
Cadmium	K1	K0.5	K1	K0.5								
Cobalt	K25	K1	K25	K1								
Chromium	K5	K0.3	K5	K0.3								
Copper	K1	K0.3	K1	K0.3								
Molybdenum	K30	K2	K30	K2								
Lead	K5	K3	K5	K3								
Tin	K50	K3	K50	K3								
Vanadium	K10	K5	K10	K5								
Yttrium	K2	K0.3	K2	K0.3								
Zinc	K5	8.6	K5	1.8								

*K indicates "less than".

PROFILE NUMBER: 2
LOCATION: T. 24N, R. 21E, Section 23, SW 1/4
SHORE TYPE: Wetland lakeward/erodible low plain landward
DATE OF COLLECTION: May 23, 1975
COLLECTORS: Wisconsin Dept. of Natural Resources and Center for Great Lakes Studies, University of Wisconsin-Milwaukee
SUPPLEMENTAL INFORMATION: Profile 1 was a landfill and rip-rap berm and no sample was collected. Profile site was reported to be a stable slope.

Sample Depth	Sample Number	Sample Description
8'(2.4 m)	B-2-1	Upper slope; no other information available.
8'(2.4 m)	B-2-2	Lower slope; no other information available.

PROFILE NUMBER: 3
LOCATION: T. 24N, R. 21E, Section 12, NW 1/4.
SHORE TYPE: Non-erodible low plain
DATE OF COLLECTION: May 23, 1975
COLLECTORS: Wisconsin Dept. of Natural Resources and Center for Great Lakes Studies, University of Wisconsin-Milwaukee
SUPPLEMENTAL INFORMATION: Profile described as a terrace.

Sample Depth	Sample Number	Sample Description
3'(0.9 m)	B-3-1	Black sandy clay and organic material.
3'(0.9 m)	B-3-2	Same as B-3-1; no other information available.

PROFILE NUMBER: 4
LOCATION: T. 25N, R. 21E, Section 36, SE 1/4.
SHORE TYPE: Wetland lakeward/erodible low plain landward
DATE OF COLLECTION: May 23, 1975
COLLECTORS: Wisconsin Dept. of Natural Resources and Center for Great Lakes Studies, University of Wisconsin-Milwaukee
SUPPLEMENTAL INFORMATION: Profile site described as a beach.

PROFILE NUMBER: 4(continued)

Sample Depth	Sample Number	Sample Description
2'(0.6 m)	B-4-1	Beach sand; vegetated; no other information available.

PROFILE NUMBER: 5
LOCATION: T. 25N, R. 22E, Section 14, SE 1/4.
SHORE TYPE: Non-erodible high bluff
DATE OF COLLECTION: May 23, 1975
COLLECTORS: Wisconsin Dept. of Natural Resources and Center for Great Lakes Studies, University of Wisconsin-Milwaukee
SUPPLEMENTAL INFORMATION: Profile site described as 10 inches soil over bedrock bluff.

Sample Depth	Sample Number	Sample Description
0-10"(0-25.4 cm)	B-5-1	Silty loam.
0-10"(0-25.4 cm)	B-5-2	Silty loam; no other information available.

PROFILE NUMBER: 6
LOCATION: T. 25N, R. 22E, Section 13, NE 1/4.
SHORE TYPE: Erodible low bluff
DATE OF COLLECTION: May 23, 1975
COLLECTORS: Wisconsin Dept. of Natural Resources and Center for Great Lakes Studies, University of Wisconsin-Milwaukee
SUPPLEMENTAL INFORMATION: Profile site described as a stable slope with 3-foot (0.9 m) bluff; this bluff height is inconsistent with reported sampling depth of 0 to 10" (0 to 25 cm); no other information available.

Sample Depth	Sample Number	Sample Description
70'(21.3 m)	B-6-1	Beach sand on calcarious red clay.
70'(21.3 m)	B-6-2	Same as B-6-1.

BROWN PROFILE 2 (mg/kg dry weight)*

Sample Depth (Number)	8'(B-2-1)		8'(B-2-2)		15"(B-2-3)							
Parameter	Total	Extr.	Total	Extr.	Total	Extr.	Total	Extr.	Total	Extr.	Total	Extr.
Total Phosphorus	1400	680	280	160	720	570						
Orthophosphate-P		670		167		570						
Total Kjeldahl Nitrogen	1800	11	130	K10	3600	53						
Nitrate/Nitrite-N		14		K6		18						
Ammonia-N		12		K9		17						
Total Organic Carbon	16000	400	3200	K100	26000	300						
Calcium	29400	10500	20600	13900	10400	5680						
Magnesium	17900	4190	14000	6190	4400	1190						
Sodium	K250	31.1	K250	19.3	K250	52.6						
Iron	15800	78.4	8900	274	6850	158						
Manganese	500	119	162	48.3	K150	11.5						
Aluminum	5600	573	2360	160	2330	467						
Titanium	160	0.4	230	0.6	95	K1						
% Total Solids (105°C)	92.5		96.2		75.4							
Specific Gravity (20°C)	2.80		2.77		2.51							
Boron	K150	5.8	K150	2.4	K150	5.5						
Barium	K50	39.6	K50	3.1	K50	16.3						
Cadmium	K1	1.0	K1	0.6	K1	K1						
Cobalt	K250	1.1	K250	1.1	K250	K2						
Chromium	K50	K0.3	K50	K0.3	K50	K1						
Copper	12	0.8	K10	K0.3	10	1.8						
Molybdenum	K300	2.7	K300	K2	K300	K5						
Lead	136	7.6	5	K3	6	K10						
Tin	K500	7.9	K500	K3	K500	K10						
Vanadium	K100	K5	K100	K5	K100	K10						
Yttrium	K20	2.2	K20	1.3	K20	K1						
Zinc	60	18.4	K50	2.1	68	8.0						

*K indicates "less than".

BROWN PROFILE 3 (mg/kg dry weight)*

Sample Depth (Number)	3'(B-3-1)		3'(B-3-2)									
Parameter	Total	Extr.	Total	Extr.	Total	Extr.	Total	Extr.	Total	Extr.	Total	Extr.
Total Phosphorus	260	150	1400	1100								
Orthophosphate-P		135		1100								
Total Kjeldahl Nitrogen	140	20	570	20								
Nitrate/Nitrite-N		K6		K6								
Ammonia-N		K9		12								
Total Organic Carbon	4100	K100	3900	200								
Calcium	44900	19900	79000	17000								
Magnesium	31800	9080	64500	8930								
Sodium	K250	37.2	376	105								
Iron	10900	497	25900	178								
Manganese	203	88.6	360	56.3								
Aluminum	2210	95	13300	418								
Titanium	280	1.5	37	K1								
% Total Solids (105°C)	92.0		87.3									
Specific Gravity (20°C)	2.75		2.33									
Boron	K150	5.0	K150	4.5								
Barium	K50	2.6	K50	17.1								
Cadmium	K1	1.2	K1	K1								
Cobalt	K250	2.6	K250	K2								
Chromium	K50	0.6	K50	K1								
Copper	10	1.0	15	K1								
Molybdenum	K300	4.7	K300	K5								
Lead	12	5.4	28	K10								
Tin	K500	21.3	K500	20.0								
Vanadium	K100	K5	K100	K10								
Yttrium	K20	2.4	K20	2.7								
Zinc	K50	2.2	51	3.4								

*K indicates "less than".

BROWN PROFILE 4 (mg/kg dry weight)*

Sample Depth (Number)	2'(B-4-1)											
Parameter	Total	Extr.	Total	Extr.	Total	Extr.	Total	Extr.	Total	Extr.	Total	Extr.
Total Phosphorus	210	210										
Orthophosphate-P		206										
Total Kjeldahl Nitrogen	280	32										
Nitrate/Nitrite-N		K6										
Ammonia-N		K9										
Total Organic Carbon	500	K100										
Calcium	17000	8870										
Magnesium	11200	5210										
Sodium	K250	52.2										
Iron	4200	248										
Manganese	K150	21.0										
Aluminum	850	54.3										
Titanium	186	K1										
% Total Solids (105°C)		85.1										
Specific Gravity (20°C)		2.71										
Boron	K150	3.6										
Barium	K50	1.0										
Cadmium	K1	K1										
Cobalt	K250	K2										
Chromium	K50	K1										
Copper	K10	K1										
Molybdenum	K300	K5										
Lead	5	K10										
Tin	K500	K10										
Vanadium	K100	K10										
Yttrium	K20	K1										
Zinc	K50	1.5										

*K indicates "less than".

BROWN PROFILE 5 (mg/kg dry weight)*

Sample Depth (Number)	(B-5-1)		(B-5-2)									
Parameter	Total	Extr.	Total	Extr.	Total	Extr.	Total	Extr.	Total	Extr.	Total	Extr.
Total Phosphorus	1100	270	730	19.0								
Orthophosphate-P		255		180								
Total Kjeldahl Nitrogen	2300	43	675	32								
Nitrate/Nitrite-N		K6		K6								
Ammonia-N		20		1.2								
Total Organic Carbon	24000	800	9600	300								
Calcium	1900	1460	4100	2860								
Magnesium	2600	329	4800	1070								
Sodium	K250	7.4	K250	13.8								
Iron	18700	118	20500	78.4								
Manganese	187	28.1	200	20.1								
Aluminum	10900	1220	14200	1000								
Titanium	309	2.5	320	1.5								
% Total Solids (105°C)	76.2		81.8									
Specific Gravity (20°C)	2.43		2.41									
Boron	K150	K2	K150	K2								
Barium	K50	29.9	K50	30.0								
Cadmium	K1	K1	K1	K1								
Cobalt	K250	K2	K250	K2								
Chromium	K50	K1	K50	K1								
Copper	K10	K1	K10	K1								
Molybdenum	K300	K5	K300	K5								
Lead	15	K10	14	K10								
Tin	K500	K10	K500	K10								
Vanadium	K100	K10	K100	K10								
Yttrium	K20	K1	K20	1.3								
Zinc	45	6.3	K50	8.6								

*K indicates "less than".

BROWN PROFILE 6 (mg/kg dry weight)*

Sample Depth (Number)	70'(B-6-1)		70'(B-6-2)									
Parameter	Total	Extr.	Total	Extr.	Total	Extr.	Total	Extr.	Total	Extr.	Total	Extr.
Total Phosphorus	200	140	650	250								
Orthophosphate-P		140		250								
Total Kjeldahl Nitrogen	300	16	280	11								
Nitrate/Nitrite-N		12		K6								
Ammonia-N		K9		10								
Total Organic Carbon	4900	K100	2300	100								
Calcium	13100	5840	58000	19700								
Magnesium	8820	3520	29000	8330								
Sodium	K250	22.0	395	85.1								
Iron	2540	148	27000	245								
Manganese	K150	17.4	415	59.5								
Aluminum	720	47.1	13500	310								
Titanium	88	0.3	310	K1								
% Total Solids (105°C)	96.8		83.4									
Specific Gravity (20°C)	2.77		2.81									
Boron	K150	2.4	K150	4.3								
Barium	K50	2.2	114	24.5								
Cadmium	K1	0.6	K1	K1								
Cobalt	K250	K1	K250	K2								
Chromium	K50	K0.3	K50	K1								
Copper	K10	K0.3	24	K1								
Molybdenum	K300	K2	K300	K5								
Lead	6	K3	21	K10								
Tin	K500	6.8	K500	27.6								
Vanadium	K100	K5	130	K10								
Yttrium	K20	K0.3	K20	2.3								
Zinc	K50	5.0	K50	3.3								

*K indicates "less than".

RACINE COUNTY, WISCONSIN

PROFILE NUMBER: 1
LOCATION: Crestview
SHORE TYPE: Erodible high bluff
DATE OF COLLECTION: June 5, 1975
COLLECTORS: Wisconsin Department of Natural Resources and the Center for Great Lakes Studies at the University of Wisconsin-Milwaukee
SUPPLEMENTAL INFORMATION:

Sample Depth	Sample Number	Sample Description
2-6"(5.1-15.2 cm)	R1-1	Al horizon; light olive gray, slightly sandy clay loam; low inorganics.
5-6'(1.5-1.8 m)	R1-2	Below top of bluff; massive, dark yellowish brown, pebbly clay till; weathered.
67'(20.4 m)	R1-3	Massive, light brownish gray to brownish gray, calcarious, pebbly clay till; fresh; approximately one foot above base of bluff.

PROFILE NUMBER: 2
LOCATION: End of 5 1/2 Mile Road
SHORE TYPE: Erodible high bluff
DATE OF COLLECTION: June 5, 1975
COLLECTORS: Wisconsin Dept. of Natural Resources and the Center for Great Lakes Studies, University of Wisconsin-Milwaukee
SUPPLEMENTAL INFORMATION:

Sample Depth	Sample Number	Sample Description
2-6"(5.1-15.2 cm)	R2-1	Al horizon; grayish brown (5YR 3/2) to dusky brown (5YR 2/2); slightly damp; sandy silt loam; moderate amount of organics.
3-4'(0.9-1.2 m)	R2-2	Thinly interbedded (beds few millimeters thick) clay, silt, and sand (very fine to fine grained); pale brown (5YR 5/2)(damp) to moderate brown (5YR 4/4) clay layers to grayish orange (10YR 7/4) to moderate yellowish brown (10YR 5/4) sand layers.
Approx. 32' (9.8 m)	R2-3	Massive, dark yellowish brown (10YR 4/2) to dusky yellowish brown (10YR 2/2) (damp) pebbly clay till; Approximately 10 feet (3 m) above base of bluff.

PROFILE NUMBER: 3
LOCATION: Wind Point Lighthouse
SHORE TYPE: Erodible high bluff
DATE OF COLLECTION: June 5, 1975
COLLECTORS: Wisconsin Dept. of Natural Resources and the Center for Great Lakes Studies, University of Wisconsin-Milwaukee
SUPPLEMENTAL INFORMATION:

Sample Depth	Sample Number	Sample Description
2-6"(5.1-15.2 cm)	R3-1	A1 horizon; silty sand; low in organics.
1-2'(0.3-0.6 m)	R3-2	Yellowish brown, silty, fine grained sand.

PROFILE NUMBER: 4
LOCATION: Adalbert Blaszczak property, 400 feet south of Case Tractor Foundary
SHORE TYPE: Erodible high bluff
DATE OF COLLECTION: June 5, 1975
COLLECTORS: Wisconsin Dept. of Natural Resources and the Center for Great Lakes Studies, University of Wisconsin-Milwaukee
SUPPLEMENTAL INFORMATION:

Sample Depth	Sample Number	Sample Description
2-6"(5.1-15.2 cm)	R4-1	A1 horizon; brownish black (dry) silty loam; moderate organics.
7-8'(2.1-2.4 m)	R4-2	Interbedded (well-defined, laterally continuance beds approximately several mm thick) fine to medium grain sand and clay; moderate yellowish brown (10YR 5/4) (wet) sand and brownish gray (5YR 4/1) (wet) clay.
Approx. 39' (11.9 m)	R4-3	Massive, light brownish gray (5YR 6/1)(damp and fresh) to olive gray pebbly sandy clay till; approximately 5 feet (1.5 m) above base of bluff.

PROFILE NUMBER: 5
LOCATION: Dr. Frank Savaglio's property, 1950 feet north of Racine/Kenosha County line
SHORE TYPE: Erodible high bluff
DATE OF COLLECTION: June 5, 1975
COLLECTORS: Wisconsin Dept. of Natural Resources and the Center for Great Lakes Studies, University of Wisconsin-Milwaukee
SUPPLEMENTAL INFORMATION:

Sample Depth	Sample Number	Sample Description
2-6"(5.1-15.2 cm)	R5-1	Al horizon; black, organic rich sandy loam.
5'(1.5 m)	R5-2	Interbedded fine sand, silt, and clay, as in Sample R4-2.
Approx. 32' (9.7 m)	R5-3	Pebbly clay till as in R4-3; approximately 4 feet (1.2 m) above base of bluff.

RACINE PROFILE 1 (mg/kg dry weight)*

Sample Depth (Number)	2-6"(R-1-1)		5'-6'(R-1-2)		67'(R-1-3)							
Parameter	Total	Extr.	Total	Extr.	Total	Extr.	Total	Extr.	Total	Extr.	Total	Extr.
Total Phosphorus	410	24	260	2	340	3						
Orthophosphate-P		16		2		K1						
Total Kjeldahl Nitrogen	3300	21	460	K10	390	10						
Nitrate/Nitrite-N		27		K6		K6						
Ammonia-N		13		K9		K9						
Total Organic Carbon	38000	600	7700	K100	4700	K100						
Calcium	13100	10200	57000	24700	75800	35800						
Magnesium	6650	1740	33300	8830	43200	8920						
Sodium	K250	14.7	K250	27.6	380	65.1						
Iron	18300	41.0	24400	251	14100	223						
Manganese	674	73.3	520	106	590	143						
Aluminum	9080	393	11300	38.7	7260	10.5						
Titanium	85	K1	225	K1	255	K1						
% Total Solids (105°C)	75.2		86.6		89.1							
Specific Gravity (20°C)	2.49		2.86		2.63							
Boron	K150	4.8	K150	4.7	K150	3.7						
Barium	80	31.4	50	10.4	K50	11.8						
Cadmium	K1	K1	1	1.2	K1	K1						
Cobalt	K250	K2	K250	K2	K250	K2						
Chromium	K50	K1	K50	K1	K50	K1						
Copper	14	K1	21	K1	12	K1						
Molybdenum	K300	K5	K300	6.0	K300	K5						
Lead	47	K10	22	K10	19	K10						
Tin	K500	K10	K500	32.7	K500	K10						
Vanadium	K100	K10	K100	K10	K100	K10						
Yttrium	K20	K1	K20	K1	K20	K1						
Zinc	74	13.2	56	1.2	82	1.4						

*K indicates "less than".

RACINE PROFILE 2 (mg/kg dry weight)*

Sample Depth (Number)	2-6"(R-2-1)		3-4'(R-2-2)		32'(R-2-3)							
Parameter	Total	Extr.	Total	Extr.	Total	Extr.	Total	Extr.	Total	Extr.	Total	Extr.
Total Phosphorus	550	85	320	5	K26	2						
Orthophosphate-P		75		K1		K1						
Total Kjeldahl Nitrogen	2800	62	130	27	K78	24						
Nitrate/Nitrite-N		28		K6		K6						
Ammonia-N		15		12		11						
Total Organic Carbon	24000	700	1400	100	4500	K100						
Calcium	9400	5940	64600	35400	75300	36800						
Magnesium	6400	1830	38100	7870	41700	8270						
Sodium	K250	15.1	250	33.7	310	29.4						
Iron	16800	43.9	12200	64.9	16500	79.2						
Manganese	215	30	327	94	470	81						
Aluminum	11600	564	5240	15.8	8920	6.3						
Titanium	104	K1	260	K1	239	K1						
% Total Solids (105°C)	81.9		86.5		87.1							
Specific Gravity (20°C)	2.42		2.65		2.67							
Boron	K150	4.8	K150	2.8	K150	3.8						
Barium	K50	40.2	K50	4.6	K50	9.9						
Cadmium	K1	K1	1	K1	K1	K1						
Cobalt	K250	K2	K250	K2	K250	K2						
Chromium	K50	K1	K50	K1	K50	K1						
Copper	22	1.9	11	K1	14	K1						
Molybdenum	K300	K5	K300	K5	K300	K5						
Lead	25	K10	22	K10	24	K10						
Tin	K500	K10	K500	K10	K500	K10						
Vanadium	K100	K10	K100	K10	K100	K10						
Yttrium	K20	K1	K20	K1	K20	K1						
Zinc	69	13.1	K50	1.3	52	K1						

*K indicates "less than".

RACINE PROFILE 3 (mg/kg dry weight)*

Sample Depth (Number)	2-6"(R-3-1)		1-2'(R-3-2)									
Parameter	Total	Extr.	Total	Extr.	Total	Extr.	Total	Extr.	Total	Extr.	Total	Extr.
Total Phosphorus	150	76	130	44								
Orthophosphate-P		69		46								
Total Kjeldahl Nitrogen	420	28	140	15								
Nitrate/Nitrite-N		30		K6								
Ammonia-N		15		10								
Total Organic Carbon	5900	200	900	K100								
Calcium	32400	16300	33700	27600								
Magnesium	19900	6390	20600	8800								
Sodium	K250	33.8	K250	30.8								
Iron	8280	328	6500	354								
Manganese	280	105	254	114								
Aluminum	1550	61.9	1170	26.8								
Titanium	290	0.5	250	0.3								
% Total Solids (105°C)	97.8		95.5									
Specific Gravity (20°C)	2.31		2.78									
Boron	K150	4.3	K150	3.6								
Barium	K50	6.4	K50	1.0								
Cadmium	K1	1.2	2	0.7								
Cobalt	K250	1.6	K250	1.6								
Chromium	K50	0.6	K50	0.5								
Copper	K10	1.1	K10	0.6								
Molybdenum	K300	2.6	K300	K2								
Lead	55	29.0	24	6.3								
Tin	K500	7.3	K500	K3								
Vanadium	K100	K5	K100	K10								
Yttrium	K20	1.1	K20	1.2								
Zinc	69	35.4	K50	17.5								

*K indicates "less than".

RACINE PROFILE 4 (mg/kg dry weight)*

Sample Depth (Number)	2-6"(R-4-1)		7-8'(R-4-2)		39'(R-4-3)							
Parameter	Total	Extr.	Total	Extr.	Total	Extr.	Total	Extr.	Total	Extr.	Total	Extr.
Total Phosphorus	800	240	250	75	320	K1						
Orthophosphate-P		240		73		K1						
Total Kjeldahl Nitrogen	2800	55	330	30	320	18						
Nitrate/Nitrite-N		60		K6		K6						
Ammonia-N		16		20		K9						
Total Organic Carbon	36000	400	9500	100	8400	K100						
Calcium	12500	5730	68900	38800	66900	25500						
Magnesium	7800	2130	38300	9860	39600	8510						
Sodium	270	27.4	260	45.0	300	41.7						
Iron	26400	160	12700	225	15300	451						
Manganese	450	111	486	133	560	170						
Aluminum	8300	590	5600	138	7460	8.2						
Titanium	148	1.6	205	K1	180	K1						
% Total Solids (105°C)	83.2		83.2		88.7							
Specific Gravity (20°C)	2.23		2.97		2.77							
Boron	K150	5.9	K150	4.3	K150	5.3						
Barium	340	84	K50	15.8	K50	4.8						
Cadmium	K1	K1	2	K1	1	1.3						
Cobalt	K250	2.6	K250	K2	K250	2.5						
Chromium	K50	K1	K50	K1	K50	K1						
Copper	56	12.6	13	1.4	24	K1						
Molybdenum	K300	K5	K300	K5	K300	K5						
Lead	253	81	25	K10	26	K10						
Tin	K500	K10	K500	K10	K500	21.1						
Vanadium	K100	K10	K100	K10	K100	K10						
Yttrium	K20	1.6	K20	2.4	K20	K1						
Zinc	420	137	50	27.1	442	3.9						

*K indicates "less than".

RACINE PROFILE 5 (mg/kg dry weight)*

Sample Depth (Number)	2-6"(R-5-1)		5'(R-5-2)		32'(R-5-3)							
Parameter	Total	Extr.	Total	Extr.	Total	Extr.	Total	Extr.	Total	Extr.	Total	Extr.
Total Phosphorus	360	120	310	K1	98	20						
Orthophosphate-P		92		K1		12						
Total Kjeldahl Nitrogen	1800	30	580	18	140	14						
Nitrate/Nitrite-N		34		K6		K6						
Ammonia-N		19		13		K9						
Total Organic Carbon	16000	K100	4700	100	3300	K100						
Calcium	37000	19200	88600	37300	74000	25200						
Magnesium	24500	7250	48500	9180	41800	8520						
Sodium	K250	26.1	280	31.6	350	58.3						
Iron	11200	119	10500	83.5	15200	467						
Manganese	250	125	410	130	580	161						
Aluminum	4120	219	3700	11.6	8000	10.9						
Titanium	160	K1	198	K1	216	K0.3						
% Total Solids (105°C)	83.4		85.0		89.2							
Specific Gravity (20°C)	2.61		2.97		2.39							
Boron	K150	4.0	K150	3.6	K150	5.3						
Barium	K50	13.2	K50	4.5	K50	12.4						
Cadmium	2	K1	1	K1	K1	1.3						
Cobalt	K250	K2	K250	2.4	K250	2.7						
Chromium	K50	K1	K50	K1	K50	K0.3						
Copper	15	2.3	11	K1	12	0.4						
Molybdenum	K300	K5	K300	K5	K300	3.7						
Lead	32	K10	26	K10	23	4.3						
Tin	K500	K10	K500	K10	K500	20.4						
Vanadium	K100	K10	K100	K10	K100	K5						
Yttrium	K20	1.1	K20	K1	K20	0.9						
Zinc	70	14.1	53	3.9	56	3.5						

*K indicates "less than".

MUSKEGON COUNTY, MICHIGAN

PROFILE NUMBER: 1
LOCATION: Approximately NE 1/4, NW 1/4, Section 23, T.9 N., R.17 W.
SHORE TYPE: High sand dune
DATE OF COLLECTION: June 5, 1975
COLLECTORS: University of Michigan Coastal Zone Laboratory
SUPPLEMENTAL INFORMATION: Sample 121-2-1 taken from face of bluff just west of other samples.

Sample Depth	Sample Number	Sample Description
0-8"(0-20.3 cm)	121-1-1	All horizon; light gray (10YR 7/2) sand; single grained; loose; neutral; gradual wavy boundary
8-13"(20.3-33.0 cm)	121-1-2	A12b horizon; pale brown (10YR 6/3) and very dark gray (10YR 3/1) sand; weak fine granular structure; very friable; neutral; gradual wavy boundary.
13-22"(20.3-55.9 cm)	121-1-3	B1 horizon; very pale brown (10YR 7/3) sand; single grained; loose; neutral; gradual irregular boundary.
22-60"(55.9-152.4 cm)	121-1-4	C horizon; pale brown (10YR 6/3) sand; grained; loose; mildly alkaline.
0-60"(0-152.4 cm)	121-2-1	C horizon; pale brown (10YR 6/3) sand; single grained; loose; mildly alkaline; slight effervescence.

PROFILE NUMBER: 2
LOCATION: NW 1/4, NW 1/4, Section 31, T.11 N., R.17 W.
SHORE TYPE: Erodible low bluff
DATE OF COLLECTION: June 5, 1975
COLLECTORS: University of Michigan Coastal Zone Laboratory
SUPPLEMENTAL INFORMATION: Samples 121-4-1 through 121-4-3 taken from face of bluff just west of other samples.

Sample Depth	Sample Number	Sample Description
0-5"(0-12.7 cm)	121-3-1	A1 horizon; dark grayish brown (10YR 4/2) sand; weak fine granular structure; very friable; slightly acid; clear wavy boundary.
5-20"(12.7-50.8 cm)	121-3-2	A2 horizon; pale brown (10YR 6/3) sand; single grained; loose; medium acid; clear irregular boundary.
20-33"(50.8-83.8 cm)	121-3-3	B2ir horizon; strong brown (7.5YR 5/6) sand; weak fine granular structure; slightly acid; gradual wavy boundary.

PROFILE NUMBER: 2(continued)

Sample Depth	Sample Number	Sample Description
33-60"(83.8-152.4 cm)	121-3-4	C horizon; light yellowish brown (10YR 6/4) sand; single grained; loose; neutral.
0-5"(0-12.7 cm)	121-4-1	A1 horizon; brown (10YR 4/3) sand; weak fine granular structure; very friable; slightly acid; abrupt smooth boundary.
5-18"(12.7-45.7 cm)	121-4-2	C1 horizon; light yellowish brown (10YR 6/4) and dark brown (7.5YR 4/4) stratified fine sand; very fine sand and silt loam, weak fine granular structure; neutral; abrupt smooth boundary.
18-60"(45.7-152.4 cm)	121-4-3	C2 horizon; pale brown (10YR 6/3) coarse sand and gravel; single grained; loose; moderately alkaline; slight effervescence.

PROFILE NUMBER: 3
LOCATION: Approximately SW 1/4, NW 1/4, Section 2, T. 11 N., R. 18 W.
SHORE TYPE: Erodible high bluff
DATE OF COLLECTION: June 5, 1975
COLLECTORS: University of Michigan Coastal Zone Laboratory
SUPPLEMENTAL INFORMATION: Sample 121-6-1 taken from face of bluff just west of other samples.

Sample Depth	Sample Number	Sample Description
0-6"(0-15.2 cm)	121-5-1	A1 horizon; brown (10YR 5/3) find sand; single grained; loose; mildly alkaline; gradual wavy boundary.
6-17"(15.2-43.2 cm)	121-5-2	C1 horizon; very pale brown (10YR 7/3) sand; single grained; loose; mildly alkaline; diffuse irregular boundary.
17-60"(43.2-152.4 cm)	121-5-3	C2 horizon; very pale brown (10YR 7/3) sand; single grained; loose; moderately alkaline; slight effervescence.
0-60"(0-152.4 cm)	121-6-1	C horizon; very pale brown (10YR 7/3) sand; single grained; loose; moderately alkaline; slight effervescence.

PROFILE NUMBER: 4
LOCATION: Approximately NW 1/4, NE 1/4, Section 22, T. 12 N., R. 18 W.
SHORE TYPE: Erodible high bluff
DATE OF COLLECTION: June 5, 1975
COLLECTORS: University of Michigan Coastal Zone Laboratory
SUPPLEMENTAL INFORMATION: Sample 121-8-1 taken from face of bluff just west of other samples.

Sample Depth	Sample Number	Sample Description
0-7"(0-17.8 cm)	121-7-1	Al horizon; brown (10YR 5/3) and very dark gray (10YR 3/1) fine sand; single grained; loose; mildly alkaline; gradual wavy boundary.
7-60"(17.8-152.4 cm)	121-7-2	C horizon; pale brown (10YR 6/3 fine sand; single grained; loose; mildly alkaline.
0-60"(0-152.4 cm)	121-8-1	C horizon; light yellowish brown (10YR 6/4) sand; single grained; loose; mildly alkaline.

MUSKEGON PROFILE 1 (mg/kg dry weight)*

Sample Depth (Number)	0-8"(121-1-1)		8-13"(121-1-2)		13-22"(121-1-3)		22-60"(121-1-4)		0-60"(121-2-1)			
Parameter	Total	Extr.	Total	Extr.	Total	Extr.	Total	Extr.	Total	Extr.	Total	Extr.
Total Phosphorus	48	26	48	20	48	23	45	21	38	18		
Orthophosphate-P		25		20		22		21		18		
Total Kjeldahl Nitrogen	58	16	120	17	60	15	16	14	19	15		
Nitrate/Nitrite-N		11		21		11		9		7		
Ammonia-N		K9		11		K9		K9		11		
Total Organic Carbon	700	100	1700	100	700	K100	500	K100	300	K100		
Calcium	1350	994	1310	1200	1150	1040	1520	842	1240	1150		
Magnesium	846	417	713	463	664	463	944	389	740	508		
Sodium	K25	8.0	K25	6.5	K25	6.4	K25	9.3	K25	7.9		
Iron	2830	25.6	2190	23.4	2590	24.9	3470	26.2	1970	29.7		
Manganese	32	9.6	26	11.1	28	9.2	40	7.9	25	8.9		
Aluminum	475	29.8	408	31.8	412	27.8	563	27.3	400	30.1		
Titanium	101	K0.3	67	K0.3	81	K0.3	213	K0.3	65	K0.3		
% Total Solids (105°C)	97.1		94.8		96.9		98.6		97.3			
Specific Gravity (20°C)	2.59		2.49		2.57		2.74		2.69			
Boron	K15	K1	K15	1.0	K15	K1	K15	K1	K15	K1		
Barium	K5	1.6	K5	1.7	K5	1.6	K5	1.5	K5	1.6		
Cadmium	K1	0.6	K1	0.6	K1	K0.5	K1	0.6	K1	0.6		
Cobalt	K25	K1	K25	K1	K25	K1	K25	K1	K25	K1		
Chromium	K5	K0.3	K5	K0.3	K5	K0.3	K5	K0.3	K5	K0.3		
Copper	K1	K0.3	K1	K0.3	K1	K0.3	K1	K0.3	K1	K0.3		
Molybdenum	K30	K2	K30	K2	K30	K2	K30	K2	K30	K2		
Lead	K5	K3	K5	K3	K5	K3	K5	K3	K5	K3		
Tin	K50	K3	K50	K3	K50	K3	K50	K3	K50	K3		
Vanadium	K10	K5	K10	K5	K10	K5	10	K5	K10	K5		
Yttrium	K2	K0.3	K2	K0.3	K2	K0.3	K2	K0.3	K2	K0.3		
Zinc	6	3.8	7	4.2	6	2.4	6	2.2	5	18.0		

*K indicates "less than".

MUSKEGON PROFILE 2 (mg/kg dry weight)*

Sample Depth (Number)	0-5"(121-3-1)		5-20"(121-3-2)		20-33"(121-3-3)		33-60"(121-3-4)		0-5"(121-4-1)		5-18"(121-4-2)	
Parameter	Total	Extr.	Total	Extr.	Total	Extr.	Total	Extr.	Total	Extr.	Total	Extr.
Total Phosphorus	85	18	48	2	92	3	35	5	160	46	65	18
Orthophosphate-P		16		2		1		4		37		18
Total Kjeldahl Nitrogen	650	39	40	10	470	45	45	17	23	15	60	17
Nitrate/Nitrite-N		29		K6		36		9		K6		10
Ammonia-N		21		K9		35		9		11		K9
Total Organic Carbon	9700	200	400	K100	9100	100	800	200	12000	K100	600	200
Calcium	741	478	1140	33.9			73	105			244	269
Magnesium	301	69.2	629	9.9			149	38.8			254	48.7
Sodium	K25	8.4	K25	9.0			K25	8.4			K25	8.3
Iron	3010	23.4	1420	10.7			1020	8.8			2550	13.7
Manganese	59	15.3	17	0.7			20	0.8			43	3.0
Aluminum	848	163	304	100			991	241			821	16.7
Titanium	108	2.3	42	0.6			27	0.3			63	0.6
% Total Solids (105°C)	90.3		99.5				95.9				92.4	
Specific Gravity (20°C)	1.99		2.69				2.72				2.68	
Boron	K15	1.1	K15	K1			K15	K1			K15	K1
Barium	K5	5.4	K5	3.0			K5	2.5			9	10
Cadmium	K1	0.7	K1	K0.3			K1	0.7			K1	0.6
Cobalt	K25	K1	K25	K1			K25	K1			K25	K1
Chromium	K5	K0.3	K5	K0.3			K5	K0.3			K5	K0.3
Copper	K1	0.3	K1	K0.3			K1	K0.3			1.4	0.4
Molybdenum	K30	K2	K30	K2			K30	K2			K30	K2
Lead	8	3.4	K5	K3			K5	K3			K5	K3
Tin	K50	K3	K50	K3			K50	K3			K50	K3
Vanadium	K10	K5	K10	K5			K10	K5			K10	K5
Yttrium	K2	K0.3	K2	K0.3			K2	K0.3			K2	2.4
Zinc	15	7.1	6	3.1			K5	2.0			K5	2.5

*K indicates "less than".

MUSKEGON PROFILE 2 (mg/kg dry weight)* continued

Sample Depth (Number)	18-60"(121-4-3)											
Parameter	Total	Extr.	Total	Extr.	Total	Extr.	Total	Extr.	Total	Extr.	Total	Extr.
Total Phosphorus	67	38										
Orthophosphate-P		34										
Total Kjeldahl Nitrogen	140	14										
Nitrate/Nitrite-N		7										
Ammonia-N		K9										
Total Organic Carbon	400	K100										
Calcium	26700	30400										
Magnesium	10000	5030										
Sodium	K250	20.0										
Iron	1740	102										
Manganese	K150	34.4										
Aluminum	649	25.5										
Titanium	82	0.4										
% Total Solids (105°C)	91.9											
Specific Gravity (20°C)	2.68											
Boron	K150	2.8										
Barium	K50	K0.3										
Cadmium	K1	0.8										
Cobalt	K250	K1										
Chromium	K50	K0.3										
Copper	K10	K0.3										
Molybdenum	K300	2.6										
Lead	K5	K3										
Tin	K500	11.9										
Vanadium	K100	K5										
Yttrium	K20	0.8										
Zinc	K50	2.5										

*K indicates "less than".

MUSKEGON PROFILE 3 (mg/kg dry weight)*

Sample Depth (Number)	0-6"(121-5-1)		6-17"(121-5-2)		17-60"(121-5-3)		0-60"(121-6-1)					
Parameter	Total	Extr.	Total	Extr.	Total	Extr.	Total	Extr.	Total	Extr.	Total	Extr.
Total Phosphorus	40	21	40	20	13	13	50	18				
Orthophosphate-P		21		18		13		15				
Total Kjeldahl Nitrogen	K38	10	25	12	K38	16	K36	14				
Nitrate/Nitrite-N		7		6		11		9				
Ammonia-N		K9		K9		11		11				
Total Organic Carbon	K300	K100	K300	K100	K300	K100	K300	K100				
Calcium	2630	2690	3240	3170	2710	2680	3890	3460				
Magnesium	1230	1080	1460	1230	1130	976	1670	1240				
Sodium	K25	8.1	K25	10.8	K25	7.4	K25	6.9				
Iron	2370	32.6	3700	23.2	2330	22.5	4800	26.7				
Manganese	20	8.0	24	6.3	18	6.1	28	6.6				
Aluminum	283	32.0	312	21.5	262	23.1	299	22.9				
Titanium	67	0.4	86	K0.3	65	K0.3	108	K0.3				
% Total Solids (105°C)	98.5		96.3		98.9		96.1					
Specific Gravity (20°C)	2.78		2.63		2.69		2.71					
Boron	K15	1.3	K15	1.3	K15	1.3	K15	1.5				
Barium	K5	1.1	K5	1.0	K5	1.2	K5	1.1				
Cadmium	K1	0.7	K1	0.6	K1	K0.5	K1	K0.5				
Cobalt	K25	K1	K25	K1	K25	K1	K25	K1				
Chromium	K5	K0.3	K5	K0.3	K5	K0.3	K5	K0.3				
Copper	K1	K0.3	K1	K0.3	K1	K0.3	K1	K0.3				
Molybdenum	K30	K2	K30	K2	K30	K2	K30	K2				
Lead	K5	K3	K5	K3	K5	K3	K5	K3				
Tin	K50	K3	K50	K3	K50	K3	K50	K3				
Vanadium	K10	K5	11	K5	K10	K5	18	K5				
Yttrium	K2	0.3	K2	K0.3	K2	K0.3	K2	K0.3				
Zinc	K5	2.3	K5	8.2	5	2.2	K5	20.4				

*K indicates "less than".

MUSKEGON PROFILE 4 (mg/kg dry weight)*

Sample Depth (Number)	0-7"(121-7-1)		7-60"(121-7-2)		0-60"(121-8-1)							
Parameter	Total	Extr.	Total	Extr.	Total	Extr.	Total	Extr.	Total	Extr.	Total	Extr.
Total Phosphorus	52	19	65	20	40	16						
Orthophosphate-P		17		17		16						
Total Kjeldahl Nitrogen	140	21	40	10	K10	K10						
Nitrate/Nitrite-N		26		7		K6						
Ammonia-N		K9		K9		K9						
Total Organic Carbon	2000	200	800	K100	K300	K100						
Calcium	1310	1230	1740	950	129	92						
Magnesium	700	541	884	456	134	13.4						
Sodium	K25	14.3	K250	13.8	K25	5.4						
Iron	4160	20.6	4890	18.7	1040	10.0						
Manganese	24	5.8	K150	2.9	K15	1.4						
Aluminum	312	29.8	319	25.4	280	36.5						
Titanium	105	K0.3	120	K0.3	27	K0.3						
% Total Solids (105°C)	95.2		95.8		96.1							
Specific Gravity (20°C)	2.71		2.63		2.79							
Boron	K15	K1	K150	K1	K15	K1						
Barium	K5	1.4	K50	1.1	K5	1.4						
Cadmium	K1	0.6	K1	K0.5	K1	0.6						
Cobalt	K25	K1	K250	K1	K25	K1						
Chromium	K5	K0.3	K50	K0.3	K5	K0.3						
Copper	K1	0.3	K10	K0.3	K1	K0.3						
Molybdenum	K30	K2	K300	K2	K30	K2						
Lead	K5	K3	K5	K3	K5	K3						
Tin	K50	K3	K500	K3	K50	K3						
Vanadium	K10	K5	K100	K5	K10	K5						
Yttrium	K2	K0.3	K20	K0.3	K2	K0.3						
Zinc	5	3.2	K50	3.0	K5	1.3						

*K indicates "less than".

MANISTEE COUNTY, MICHIGAN

PROFILE NUMBER: 1
LOCATION: Section 15, T. 21 N, R. 17 W.
SHORE TYPE: Erodible high bluff
DATE OF COLLECTION: June 6, 1975
COLLECTORS: University of Michigan Coastal Zone Laboratory
SUPPLEMENTAL INFORMATION: Samples 101-2-1 and 101-2-2 taken from face of bluff just west of other samples.

Sample Depth	Sample Number	Sample Description
0-7"(0-17.8 cm)	101-1-1	A1 horizon; very dark grayish brown (10YR 3/2) loam; moderate medium granular structure; friable; neutral; gradual wavy boundary.
7-15"(17.8-38.1 cm)	101-1-2	B & A horizons; pale brown (10YR 6/3) and brown (7.5YR 5/4) clay loam; moderate medium subangular blocky structure; firm; neutral; gradual wavy boundary.
15-24"(38.1-61.0 cm)	101-1-3	B2t horizon; brown (7.5YR 5/4) heavy clay loam; moderate firm; neutral; gradual wavy boundary.
24-60"(61.0-152.4 cm)	101-1-4	C horizon; brown (7.5YR 5/4) clay loam; moderate coarse angular blocky structure; firm; moderately alkaline; slight effervescence.
0-10"(0-25.4 cm)	101-2-1	C1 horizon; brown (7.5YR 5/4) clay loam; weak medium angular blocky structure; firm; slight effervescence.
10-60"(25.4-152.4 cm)	101-2-2	C2 horizon; light brown (7.5YR 6/4) silt loam; massive; friable; slight effervescence.

PROFILE NUMBER: 2
LOCATION: Section 16, T. 24 N., R. 16 W.
SHORE TYPE: Erodible low bluff
DATE OF COLLECTION: June 6, 1975
COLLECTORS: University of Michigan Coastal Zone Laboratory
SUPPLEMENTAL INFORMATION: Samples 101-4-1 and 101-4-2 taken from face of bluff just west of other samples.

Sample Depth	Sample Number	Sample Description
0-12"(0-30.5 cm)	101-3-1	A horizon; brown (10YR 5/3) sand; single grained; loose; mildly alkaline; gradual wavy boundary.
12-60"(30.5-152.4 cm)	101-3-2	C horizon; pale brown (10YR 6/3) sand; single grained; loose; slight effervescence; moderately alkaline.

PROFILE NUMBER: 2(continued)

Sample Depth	Sample Number	Sample Description
0-10"(0-25.4 cm)	101-4-1	A horizon; brown (10YR 5/3) sand; single grained; loose; slight effervescence; gradual wavy boundary.
10-60"(25.4-152.4 cm)	101-4-2	C horizon; very pale brown (10YR 7/3) sand; single grained; loose; slight effervescence.

PROFILE NUMBER: 3
LOCATION: Section 3, T. 24 N., R. 16 W.
SHORE TYPE: Erodible high bluff
DATE OF COLLECTION: June 6, 1975
COLLECTORS: University of Michigan Coastal Zone Laboratory
SUPPLEMENTAL INFORMATION: Sample 101-6-1 taken from face of bluff just west of other samples.

Sample Depth	Sample Number	Sample Description
0-20"(0-50.8 cm)	101-5-1	A1 horizon; pale brown (10YR 6/3) fine sand; single grained; loose; neutral, abrupt smooth boundary.
20-24"(50.8-61.0 cm)	101-5-2	IIA1 b horizon; black (10YR 2/1) silty clay loam; weak medium subangular blocky structure; firm; mildly alkaline; gradual wavy boundary.
24-27"(61.0-68.6 cm)	101-5-3	IIB2 horizon; reddish brown (5YR 5/3) silty clay loam; moderate medium angular blocky structure; firm; mildly alkaline; abrupt smooth boundary.
27-60"(68.6-152.4 cm)	101-5-4	IIIC horizon; pale brown (10YR 6/3) sand; single grained; loose; moderately alkaline.
0-60"(0-152.4 cm)	101-6-1	C horizon; light yellowish brown (10YR 6/4) sand; single grained; loose; moderately alkaline.

MANISTEE PROFILE 1 (mg/kg dry weight)*

Sample Depth (Number)	0-7"(101-1-1)		7-15"(101-1-2)		15-24"(101-1-3)		24-60"(101-1-4)		0-10"(101-2-1)		10-60"(101-2-2)	
Parameter	Total	Extr.	Total	Extr.	Total	Extr.	Total	Extr.	Total	Extr.	Total	Extr.
Total Phosphorus	610	200	230	150	240	46	390	57	370	41	80	35
Orthophosphate-P		196		147		21		44		25		16
Total Kjeldahl Nitrogen	1700	47	280	70	210	27	340	15	340	23	34	K10
Nitrate/Nitrite-N		39		K6		16		6		12		K6
Ammonia-N		K9		11		18		9		12		K9
Total Organic Carbon	2500	600	2400	200	1000	K100	1000	K100	1500	K100	500	K100
Calcium	8640	8510	2640	2600	38100	28500	55700	37400	46800	35800	61300	35400
Magnesium	5010	1990	2900	708	23700	11200	26200	8690	22500	9510	28000	9390
Sodium	K250	40.9	K250	20.8	K250	35.3	K250	39.2	K250	40.4	K250	27.8
Iron	13400	75.1	7890	154	8350	2.8	1086	0.8	9180	3.3	4650	3.3
Manganese	510	81.3	150	20.6	294	41.6	355	34.4	239	74.6	180	53.5
Aluminum	12700	834	7550	671	6820	K10	9120	K10	7240	K10	2920	K10
Titanium	290	1.4	170	2.7	255	K0.3	420	K0.3	301	K0.3	182	0.3
% Total Solids (105°C)	82.8		91.1		88.4		87.2		85.7		88.1	
Specific Gravity (20°C)	2.32		2.64		2.58		2.44		2.51		2.68	
Boron	K150	6.5	K150	2.1	K150	5.5	K150	3.7	K150	4.9	K150	4.5
Barium	K50	91.1	K50	42.1	K50	7.7	62	4.9	57	11.3	K50	4.7
Cadmium	K1	1.1	K1	0.6	1	0.9	1	0.6	1	0.7	K1	0.7
Cobalt	K250	K1	K250	K1	K250	K1	K250	K1	K250	K1	K250	K1
Chromium	K50	0.4	K50	0.3	K50	0.7	K50	0.3	K50	0.4	K50	0.5
Copper	K10	7.5	K10	0.9	K10	K0.3	15	K0.3	12	K0.3	K10	K0.3
Molybdenum	K300	2.0	K300	K2	K300	2.2	K300	K2	K300	K2	K300	K2
Lead	132	68.3	8	3.6	14	K3	18	K3	19	K3	17	K3
Tin	K500	K3	K500	K3	K500	4.3	K500	5.0	K500	7.4	K500	K3
Vanadium	K100	K5	K100	K5	K100	K5	120	K5	K100	K5	K100	K5
Yttrium	K10	2.0	K10	2.0	K10	0.5	K10	0.5	K10	0.5	K10	0.5
Zinc	150	71.8	K50	5.2	K50	0.8	K50	0.9	K50	2.2	K50	0.4

*K indicates "less than".

MANISTEE PROFILE 2 (mg/kg dry weight)*

Sample Depth (Number)	0-12"(101-3-1)		12-60"(101-3-2)		0-10"(101-4-1)		10-60"(101-4-2)					
Parameter	Total	Extr.	Total	Extr.	Total	Extr.	Total	Extr.	Total	Extr.	Total	Extr.
Total Phosphorus	19	12	40	17	97	35	65	29				
Orthophosphate-P		12		14		36		29				
Total Kjeldahl Nitrogen	78	17	30	19	120	23	83	K10				
Nitrate/Nitrite-N		8		7		7		6				
Ammonia-N		10		9		11		K9				
Total Organic Carbon	600	K100	2400	K100	800	100	2400	K100				
Calcium	9870	3650	9820	11400	19900	14500	23300	15900				
Magnesium	4070	1340	3810	3770	8060	4980	8500	4650				
Sodium	32	12.5	K25	14.7	K250	22.1	K250	14.4				
Iron	1440	19.4	1000	56.7	8050	77.0	1500	70.9				
Manganese	22	6.8	17	9.2	K150	11.8	K150	11.4				
Aluminum	314	19.4	283	17.1	637	20.3	444	17.6				
Titanium	51	K0.3	29	K0.3	289	0.4	83	0.3				
% Total Solids (105°C)	98.2		96.2		97.5		96.5					
Specific Gravity (20°C)	2.70		2.81		2.79		2.86					
Boron	K15	1.5	K15	2.4	K150	2.3	K150	1.9				
Barium	K5	0.8	K5	K0.3	K50	0.6	K50	K0.3				
Cadmium	K1	0.5	K1	0.7	K1	0.7	K1	0.5				
Cobalt	K25	K1	K25	K1	K250	K1	K250	K1				
Chromium	K5	K0.3	K5	K0.3	K50	0.3	K50	K0.3				
Copper	K1	K0.3	K1	K0.3	K10	K0.3	K10	K0.3				
Molybdenum	K30	K2	K30	K2	K300	K2	K300	K2				
Lead	K5	K3	K5	K3	5	K3	K5	K3				
Tin	K50	K3	K50	K3	K500	K3	K500	K3				
Vanadium	20	K5	K10	K5	K100	K5	K100	K5				
Yttrium	1.5	K0.3	K1	K0.3	K10	0.7	K10	0.4				
Zinc	5.5	6.4	K5	6.9	K50	3.5	K50	2.7				

*K indicates "less than".

MANISTEE PROFILE 3 (mg/kg dry weight)*

Sample Depth (Number)	0-20"(101-5-1)		20-24"(101-5-2)		24-27"(101-5-3)		27-60"(101-5-4)		0-60"(101-6-1)			
Parameter	Total	Extr.	Total	Extr.	Total	Extr.	Total	Extr.	Total	Extr.	Total	Extr.
Total Phosphorus	45	24	670	74	320	100	25	16	48	20		
Orthophosphate-P		23		73		100		14		19		
Total Kjeldahl Nitrogen	50	11	2400	40	450	46	25	10	25	16		
Nitrate/Nitrite-N		15		50		36		K6		K6		
Ammonia-N		10		9		27		K9		9		
Total Organic Carbon	1200	K100	21000	500	3700	200	K300	K100	1100	K100		
Calcium	6580	4690	7400	5820	9210	8010	11000	9380	5670	3340		
Magnesium	2860	1990	4500	1310	7850	3370	4150	3150	3410	1790		
Sodium	K250	6.6	K250	15.5	K250	26.6	27	7.9	K25	9.4		
Iron	5800	32.9	17500	72.1	14300	200	1650	43.1	1190	37.4		
Manganese	K150	5.8	465	80.6	333	32.0	19	7.3	17	6.2		
Aluminum	350	21.5	12800	1140	12900	83.8	226	16.8	462	70.4		
Titanium	270	K0.3	430	2.2	285	2.9	47	K0.3	30	0.4		
% Total Solids (105°C)	98.2		78.8		82.4		97.6		96.4			
Specific Gravity (20°C)	2.82		2.75		2.39		2.74		2.70			
Boron	K150	1.5	K150	2.5	K150	2.0	K15	1.5	K15	1.8		
Barium	K50	0.4	96	56.2	K50	63.3	K5	K0.3	K5	2.0		
Cadmium	K1	0.5	K1	1.1	K1	0.9	K1	0.6	K1	0.6		
Cobalt	K250	K1	K250	K2	K250	K1	K25	K1	K25	K1		
Chromium	K50	K0.3	K50	K1	K50	0.4	K5	K0.3	K5	K0.3		
Copper	K10	K0.3	14	1.3	17	2.7	K1	0.4	K1	K0.3		
Molybdenum	K300	K2	K300	K5	K300	K2	K30	K2	K30	K2		
Lead	K5	K3	13	K5	10	K3	K5	K3	K5	K3		
Tin	K500	K3	K500	K5	K500	K3	K50	K3	K50	K3		
Vanadium	K100	K5	K100	K10	K100	K5	16	K5	K10	K5		
Yttrium	K10	K0.3	K10	1.6	K10	2.8	K1	K0.3	K1	0.4		
Zinc	K50	1.6	K50	4.7	K50	4.6	K5	1.6	K5	2.8		

*K indicates "less than".

SCHOOLCRAFT COUNTY, MICHIGAN

PROFILE NUMBER: 1
LOCATION: South of Gulliver; approximately SE 1/4, SE 1/4, SE 1/4, Section 11, T41N, R14W.
SHORE TYPE: Low sand dune
DATE OF COLLECTION: June 23-25, 1975
COLLECTORS: University of Michigan Coastal Zone Laboratory
SUPPLEMENTAL INFORMATION: Samples 153-1-2 and 153-1-3 taken from face of bluff just east of other samples.

Sample Depth	Sample Number	Sample Description
0-60"(0-152.4 cm)	153-1-1	C1 horizon; very pale brown (10YR 7/3) sand; single grained; loose; common roots in upper 18 inches; effervescent.
0-50"(0-127.0 cm)	153-1-2	C1 horizon; very pale brown (10YR 7/3) sand; single grained; loose; effervescent; clear smooth boundary.
50-60"(127.0-152.4 cm)	153-1-3	C2 horizon; light yellowish brown (10YR 6/4-wet) sand; single grained; common medium faint strong brown (7.5YR 5/6) mottles in lower 4 inches; many bark fragments and pieces of branches; nonsticky; effervescent; water at 60 inches.

PROFILE NUMBER: 2
LOCATION: At County Park, east of Manistique; approximately SW 1/4, NE 1/4, Section 11, T41N, R15W.
SHORE TYPE: Non-erodible low plain (Despite this classification assigned by the U.S. Army Corps of Engineers, there is evidence that this bluff erodes.)
DATE OF COLLECTION: June 23-25, 1975
COLLECTORS: University of Michigan Coastal Zone Laboratory
SUPPLEMENTAL INFORMATION: Water table at approximately 150 cm.

Sample Depth	Sample Number	Sample Description
0-50"(0-127.0 cm)	153-2-1	C1 horizon; light gray (10YR 7/2) sand; single grained; loose; common roote in upper 24 inches; effervescent; abrupt smooth boundary.
50-60"(127.0-152.4 cm)	153-2-2	A1b horizon; dark grayish brown (10YR 4/2) sand; single grained; loose; many medium faint dark gray (10YR 4/1) and few fine distinct reddish yellow (7.5YR 6/6) mottles; common root fragments and wood chips; effervescent.

PROFILE NUMBER: 3
LOCATION: South of Coast Guard Station in Section 18, T41N, R14W.
SHORE TYPE: Low sand dune
DATE OF COLLECTION: June 23-25, 1975
COLLECTORS: University of Michigan Coastal Zone Laboratory
SUPPLEMENTAL INFORMATION: Water table at about 130 cm; C1 horizon (0-5 inches) was not sampled but consisted of white (10YR 8/1) limestone cobbles and flags, 2-10 inches in diameter. It was also effervescent and had a clear smooth boundary.

Sample Depth	Sample Number	Sample Description
5-18"(12.7-45.7 cm)	153-3-1	IIC2 horizon; very pale brown very gravelly and cobbly sand; single grained; loose; 80 percent limestone gravelly and cobbles to 6 inches in diameter; effervescent; abrupt smooth boundary.
18-23"(45.7-58.4 cm)	153-3-2	IIIC3 horizon; very pale brown (10YR 7/3) sand; single grained; loose; about 50 percent wood fragments; 1/2-1 inch in diameter and up to 12 inches long; effervescent; abrupt smooth boundary.
23-26"(58.4-66.0 cm)	153-3-3	IVC4 horizon; dark grayish brown (10YR 4/2) very gravelly loamy sand; massive; firm; over 90 percent angular limestone fragments 1/8-3/4 inch in diameter; effervescent; abrupt smooth boundary.
26-29"(66.0-73.7 cm)	153-3-4	IVC5 horizon; brown (10YR 5/3) very gravelly loamy sand; massive; firm; over 90 percent angular limestone fragments 1/8-3/4 inch in diameter; effervescent; abrupt smooth boundary.
29-30"(73.7-76.2 cm)	153-3-5	VA1b horizon; dark gray (10YR 4/1) very gravelly loamy sand; single grained; loose; 80 percent angular limestone fragments 1-3 inches in diameter; effervescent; abrupt smooth boundary.
30-39"(76.2-99.1 cm)	153-3-6	VIC1b horizon; very pale brown (10YR 7/3) sand; single grained; loose; effervescent; clear smooth boundary.
39-54"(99.1-137.2 cm)	153-3-7	VIIC1b horizon; yellowish brown (10YR 5/4) sand; single grained; non-sticky; common black (10YR 2/1) and dark grayish brown (10YR 4/2) streaks and blotches of organic material; effervescent.

PROFILE NUMBER: 4
LOCATION: East of Thompson at roadside park; approximately SW 1/4, NE 1/4, Section 28, T41N, R16W.
SHORE TYPE: Low sand dune
DATE OF COLLECTION: June 23-25, 1975
COLLECTORS: University of Michigan Coastal Zone Laboratory
SUPPLEMENTAL INFORMATION: Water table at approximately 70 cm.

Sample Depth	Sample Number	Sample Description
0-11"(0-27.9 cm)	153-4-1	C1 horizon; light gray (10YR 7/2) sand; single grained; loose; few live roots; effervescent; abrupt smooth boundary.
11-14"(27.9-35.6 cm)	153-4-2	Alb1 horizon; very dark gray (10YR 3/1) sand; very weak fine granular structure; very friable; few fine prominent yellowish red (5YR 5/3) and many medium faint dark gray (10YR 4/1) mottles; 10-15 percent woody fragments; effervescent; abrupt smooth boundary.
14-22"(35.6-55.9 cm)	153-4-3	Clb horizon; light gray (10YR 7/2) sand; single grained; loose; few fine prominent yellowish red and few medium distinct strong brown (7.5YR 5/6) and redish yellow (7.5YR 6/6) mottles; less than 2 percent woody fragments; effervescent; abrupt smooth boundary.
22-24"(55.9-61.0 cm)	153-4-4	Alb2 horizon; gray (10YR 5/1)--dark gray (10YR 5/1) in upper 1/3 or horizon--sand; single grained; non-sticky; 30-50 percent woody fragments; effervescent; abrupt smooth boundary.
24-50"(61.0-127.0 cm)	153-4-5	Clb2 horizon; grayish brown (10YR 5/2) sand; single grained; non-sticky; effervescent; log at 50 cm.

PROFILE NUMBER: 5
LOCATION: South of Thompson; approximately NE 1/4, NW 1/4, Section 10, T39N, R17W.
SHORE TYPE: Non-erodible low plain (Despite this classification assigned by the U.S. Army Corps of Engineers, there is evidence that some erosion does take place.)
DATE OF COLLECTION: June 23-25, 1975
COLLECTORS: University of Michigan Coastal Zone Laboratory
SUPPLEMENTAL INFORMATION: Water table at approximately 75 cm.

PROFILE NUMBER: 5(continued)

Sample Depth	Sample Number	Sample Description
0-11"(0-27.9 cm)	153-5-1	Cl horizon; light gray (10YR 7/2) sand; single grained; loose; effervescent; abrupt smooth boundary.
11-17"(27.9-43.2 cm)	153-5-2	Alb horizon; dark gray (10YR 4/1) sand; very weak fine granular structure; discontinuous very dark brown (10YR 2/2) organic layer 1 inch thick at top of this horizon; very friable; effervescent; clear smooth boundary.
17-50"(43.2-127.0 cm)	153-5-3	Clb horizon; light gray (10YR 7/2) sand; single grained; non-sticky; common fine and medium, prominent yellowish red (5YR 5/8) mottles in upper 19 inches; effervescent.

SCHOOLCRAFT PROFILE 1 (mg/kg dry weight)*

Sample Depth (Number)	0-60"(153-1-1)		0-50"(153-1-2)		50-60"(153-1-3)							
Parameter	Total	Extr.	Total	Extr.	Total	Extr.	Total	Extr.	Total	Extr.	Total	Extr.
Total Phosphorus	60	27	80	24	30	16						
Orthophosphate-P		27		24		15						
Total Kjeldahl Nitrogen	30	19	K38	12	32	18						
Nitrate/Nitrite-N		13		9		8						
Ammonia-N		15		11		K9						
Total Organic Carbon	400	K100	K300	K100	400	200						
Calcium	1960	1900	1550	1300	1920	975						
Magnesium	1090	954	860	647	123	86.0						
Sodium	K25	10.4	124	6.8	K25	8.1						
Iron	2050	51.5	4990	47.8	1170	61.1						
Manganese	18	7.0	114	4.7	K15	0.8						
Aluminum	227	21.6	771	21.1	196	34.3						
Titanium	49	K0.3	76	K0.3	21	K1						
% Total Solids (105°C)	99.1		96.6		81.4							
Specific Gravity (20°C)	2.72		2.78		2.60							
Boron	K15	1.1	K15	K1	K15	K2						
Barium	K5	0.9	16	0.7	K10	1.6						
Cadmium	K1	K0.5	K1	0.5	K1	K1						
Cobalt	K25	K1	317	K1	K25	K2						
Chromium	K5	K0.3	963	K0.3	K5	K1						
Copper	K1	K0.3	15	K0.3	K1	K1						
Molybdenum	K30	K2	K30	K2	K30	K5						
Lead	K5	K3	K5	K3	K5	K10						
Tin	K50	K3	K50	K3	K50	K10						
Vanadium	K10	K5	K10	K5	K10	K10						
Yttrium	K2	K0.3	K2	K0.3	K2	K1						
Zinc	K5	2.3	6	2.6	K5	21.1						

*K indicates "less than".

SCHOOLCRAFT PROFILE 2 (mg/kg dry weight)*

Sample Depth (Number)	0-50"(153-2-1)		50-60"(153-2-2)									
Parameter	Total	Extr.	Total	Extr.	Total	Extr.	Total	Extr.	Total	Extr.	Total	Extr.
Total Phosphorus	40	18	40	8								
Orthophosphate-P		18		8								
Total Kjeldahl Nitrogen	45	11	180	14								
Nitrate/Nitrite-N		8		8								
Ammonia-N		K9		K9								
Total Organic Carbon	400	100	3400	K100								
Calcium	4140	4120	4730	3890								
Magnesium	2400	2120	2830	2030								
Sodium	K25	10.9	K25	10.0								
Iron	1200	50.7	1360	40.0								
Manganese	17	8.0	17	7.0								
Aluminum	229	21.1	268	20.0								
Titanium	25	K0.3	28	K1								
% Total Solids (105°C)	99.2		78.3									
Specific Gravity (20°C)	2.76		2.64									
Boron	K15	1.4	K15	1.9								
Barium	K5	0.7	K10	1.2								
Cadmium	K1	0.6	K1	K0.5								
Cobalt	K25	K1	K25	K2								
Chromium	K5	K0.3	K5	K1								
Copper	K1	K0.3	K1	K1								
Molybdenum	K30	K2	K30	K5								
Lead	K5	K3	K5	K10								
Tin	K50	K3	K50	K10								
Vanadium	K10	K5	K10	K10								
Yttrium	K2	K0.3	K2	K1								
Zinc	K5	17.4	K5	3.8								

*K indicates "less than".

SCHOOLCRAFT PROFILE 3 (mg/kg dry weight)*

Sample Depth (Number)	29-30"(153-3-5)		30-39"(153-3-6)		39-54"(153-3-7)							
Parameter	Total	Extr.	Total	Extr.	Total	Extr.	Total	Extr.	Total	Extr.	Total	Extr.
Total Phosphorus	K22	6	32	9	42	17						
Orthophosphate-P		3		9		17						
Total Kjeldahl Nitrogen	K67	18	14	K10	68	K10						
Nitrate/Nitrite-N		7		K6		K6						
Ammonia-N		10		K9		K9						
Total Organic Carbon	11000	200	300	K100	1600	K100						
Calcium	57900	32700	1290	860	286	353						
Magnesium	27500	8590	736	407	110	43.8						
Sodium	K250	31.6	K25	6.2	K25	35.7						
Iron	2000	1.1	1140	43.6	1090	61.0						
Manganese	220	21.4	K15	3.4	K15	4.0						
Aluminum	1470	5.4	267	27.9	303	52.0						
Titanium	70	K0.3	24	K0.3	20	K1						
% Total Solids (105°C)	94.3		90.7		82.8							
Specific Gravity (20°C)			2.80		2.64							
Boron	K150	4.0	K15	K1	K15	K2						
Barium	K50	2.3	K5	1.1	K5	2.0						
Cadmium	1	0.6	K1	0.6	K1	0.8						
Cobalt	K250	K1	K25	K1	K25	K2						
Chromium	K50	0.3	K5	K0.3	K5	K1						
Copper	K10	K0.3	K1	K0.3	K1	K1						
Molybdenum	K300	K2	K30	K2	K30	K5						
Lead	K30	K3	K5	K3	K5	K10						
Tin	K500	5.5	K50	K3	K50	K10						
Vanadium	120	K5	K10	K5	K10	K10						
Yttrium	K20	0.3	K2	K0.3	K2	K1						
Zinc	K50	11.0	K5	2.5	K5	4.3						

*K indicates "less than".

SCHOOLCRAFT PROFILE 4 (mg/kg dry weight)*

Sample Depth (Number)	11-14"(153-4-2)		14-22"(153-4-3)		22-24"(153-4-4)		24-50"(153-4-5)					
Parameter	Total	Extr.	Total	Extr.	Total	Extr.	Total	Extr.	Total	Extr.	Total	Extr.
Total Phosphorus	200	39	52	38	60	52	60	27				
Orthophosphate-P		39		37		45		27				
Total Kjeldahl Nitrogen	280	15	42	18	75	22	25	18				
Nitrate/Nitrite-N		9		K6		K6		16				
Ammonia-N		9		9		13		13				
Total Organic Carbon	5700	200	500	K100	2400	100	700	K100				
Calcium	5880	4780	6220	5910	4960	5150	4220	2880				
Magnesium	2730	2420	3600	3270	2960	2790	2490	1380				
Sodium	56	11.0	29	13.4	35	25.6	K25	11.9				
Iron	2580	135	2020	98.8	2580	84.6	2400	44.5				
Manganese	81	50	19	7.3	23	7.0	19	4.1				
Aluminum	794	98.1	282	34.2	393	44.1	256	23.0				
Titanium	69	K1	54	K1	113	K1	87	K1				
% Total Solids (105°C)	76.1		81.9		79.0		81.0					
Specific Gravity (20°C)	2.72		2.82		2.76		2.87					
Boron	K15	2.1	K15	2.1	K15	K2	K15	K2				
Barium	17		K5	1.3	K5	1.2	K5	K1				
Cadmium	K1	K1	K1	K1	K1	K1	K1	K1				
Cobalt	K25	K2	K25	K2	K25	K2	K25	K2				
Chromium	K5	K1	K5	K1	K5	K1	K5	K1				
Copper	4	K1	K1	K1	K1	K1	K1	K1				
Molybdenum	K30	K5	K30	K5	K30	K5	K30	K5				
Lead	14	10.4	K5	K10	K5	K10	K5	K10				
Tin	K50	K10	K50	K10	K50	K10	K50	K10				
Vanadium	16	K10	13	K10	13	K10	10	K10				
Yttrium	K2	K1	K2	K1	K2	K1	K2	K1				
Zinc	53	23.6	5	10.9	5	3.3	K5	2.9				

*K indicates "less than".

SCHOOLCRAFT PROFILE 5 (mg/kg dry weight)*

Sample Depth (Number)	0-11"(153-5-1)		11-17"(153-5-2)		17-50"(153-5-3)							
Parameter	Total	Extr.	Total	Extr.	Total	Extr.	Total	Extr.	Total	Extr.	Total	Extr.
Total Phosphorus	25	16	13	17	37	7						
Orthophosphate-P		13		13		4						
Total Kjeldahl Nitrogen	46	28	230	17	150	16						
Nitrate/Nitrite-N		28		9		7						
Ammonia-N		15		K9		K9						
Total Organic Carbon	2200	K100	1900	200	1500	K100						
Calcium	11900	8380	14700	9140	11400	3760						
Magnesium	6830	4310	8490	4600	6560	2040						
Sodium	K250	15.7	K250	15.8	K250	13.4						
Iron	935	33.9	1200	32.4	992	197						
Manganese	K150	5.8	K150	12.3	K150	2.1						
Aluminum	220	22.9	250	20.4	177	11.5						
Titanium	31	K0.3	37	K0.3	17	K0.3						
% Total Solids (105°C)	98.5		93.0		89.5							
Specific Gravity (20°C)	2.62		2.63		2.92							
Boron	K150	1.8	K150	1.8	K150	1.4						
Barium	K50	K0.3	K50	0.9	K50	0.6						
Cadmium	K1	0.7	K1	0.6	K1	0.6						
Cobalt	K250	K1	K250	K1	K250	K1						
Chromium	K50	K0.3	K50	K0.3	K50	K0.3						
Copper	K10	K0.3	K10	K0.3	K10	K0.3						
Molybdenum	K300	K2	K300	K2	K300	K2						
Lead	K5	K3	K5	K3	K5	K3						
Tin	K500	K3	K500	K3	K500	K3						
Vanadium	K100	K5	K100	K5	K100	K5						
Yttrium	K20	0.3	K20	K0.3	K20	K0.3						
Zinc	K50	2.2	K50	3.4	K50	3.7						

*K indicates "less than".

ALCONA COUNTY, MICHIGAN

PROFILE NUMBER: 1
LOCATION: Section 14, T. 25 N., R. 9 E.
SHORE TYPE: Erodible low plain
DATA OF COLLECTION: June 19, 1975
COLLECTORS: University of Michigan Coastal Zone Laboratory
SUPPLEMENTAL INFORMATION: Sample 001-2-1 taken from face of bluff just east of other samples.

Sample Depth	Sample Number	Sample Description
0-7"(0-17.8 cm)	001-1-1	Al horizon; light yellowish brown (10YR 6/4) sand; single grained; loose; mildly alkaline; diffuse wavy boundary.
7-60"(17.8-152.4 cm)	001-1-2	C horizon; pale brown (10YR 6/3) sand; single grained; loose; slight effervescence.
0-60"(0-152.4 cm)	001-2-1	C horizon; pale brown (10YR 6/3) sand; single grained; loose; slight effervescence.

PROFILE NUMBER: 2
LOCATION: Section 12, T. 27 N., R. 9 E.
SHORE TYPE: Erodible low plain lakeward/wetlands landward
DATE OF COLLECTION: June 19, 1975
COLLECTORS: University of Michigan Coastal Zone Laboratory
SUPPLEMENTAL INFORMATION: Sample 001-4-1 taken from face of bluff just east of other samples.

Sample Depth	Sample Number	Sample Description
0-7"(0-17.8 cm)	001-3-1	Al horizon; brown (10YR 5/3) sand; single grained; loose; mildly alkaline; gradual wavy boundary.
7-24"(17.8-61.0 cm)	001-3-2	Cl horizon; light yellowish brown (10YR 6/4) sand; single grained; loose; mildly alkaline; gradual wavy boundary.
24-60"(61.0-152.4 cm)	001-3-3	C2 horizon; pale brown (10YR 6/3) sand; single grained; loose; slight effervescence.
0-60"(0-152.4 cm)	001-4-1	Cl horizon; pale brown (10YR 6/3) sand; single grained; loose; effervescent.

PROFILE NUMBER: 3
LOCATION: T. 28 N., R. 9 E.
SHORE TYPE: Erodible low plain
DATE OF COLLECTION: June 19, 1975
COLLECTORS: University of Michigan Coastal Zone Laboratory
SUPPLEMENTAL INFORMATION: No bluff along this profile; water table at approximately 25.4 cm.

Sample Depth	Sample Number	Sample Description
0-2"(0-5.1 cm)	001-5-1	A1 horizon; very dark gray (10YR 3/1) loamy fine sand; weak fine granular structure; very friable; neutral gradual smooth boundary.
8-60"(20.3-152.4 cm)	001-5-2	Cg horizon; gray (10YR 5/1) fine sand; single grained; loose; mildly alkaline.

ALCONA PROFILE 1 (mg/kg dry weight)*

Sample Depth (Number)	0-7"(001-1-1)		7-60"(001-1-2)		0-60"(001-2-1)							
Parameter	Total	Extr.	Total	Extr.	Total	Extr.	Total	Extr.	Total	Extr.	Total	Extr.
Total Phosphorus	70	35	45	24	21	23						
Orthophosphate-P		30		24		19						
Total Kjeldahl Nitrogen	13	K10	K33	18	9.0	K10						
Nitrate/Nitrite-N		10		K6		7						
Ammonia-N		K9		9		K9						
Total Organic Carbon	400	K100	400	K100	300	100						
Calcium	4100	4220	3400	3340	6810	4440						
Magnesium	2400	1990	1800	1520	3100	1700						
Sodium	30	11	36	14	35	11						
Iron	3100	54.7	2100	52.8	2300	52.6						
Manganese	28	9.1	25	7.3	28	8.8						
Aluminum	499	19.0	534	18.4	531	14.2						
Titanium	122	K0.3	127	K0.3	106	K0.3						
% Total Solids (105°C)	97.7		95.1		96.7							
Specific Gravity (20°C)	2.65		2.79		2.73							
Boron	K15	1.3	K15	1.4	K15	1.3						
Barium	K5	0.6	K5	0.7	K5	0.4						
Cadmium	K1	0.6	K1	K0.5	K1	K0.5						
Cobalt	K25	K1	K25	K1	K25	K1						
Chromium	K5	K0.3	K5	K0.3	K5	K0.3						
Copper	K1	K0.3	K1	K0.3	K1	K0.3						
Molybdenum	K30	K2	K30	K2	K30	K2						
Lead	K5	K3	K5	K3	K5	K3						
Tin	K50	K3	K50	K3	K50	K3						
Vanadium	14	K5	K10	K5	12	K5						
Yttrium	K2	K0.3	K2	K0.3	K2	K0.3						
Zinc	7	4.0	6	5.1	6	1.6						

*K indicates "less than".

ALCONA PROFILE 2 (mg/kg dry weight)*

Sample Depth (Number)	0-7"(001-3-1)		7-24"(001-3-2)		24-60"(001-3-3)		0-60"(001-4-1)					
Parameter	Total	Extr.	Total	Extr.	Total	Extr.	Total	Extr.	Total	Extr.	Total	Extr.
Total Phosphorus	62	30	52	27	61	32	52	31				
Orthophosphate-P		28		27		32		30				
Total Kjeldahl Nitrogen	85	16	42	11	160	12	28	21				
Nitrate/Nitrite-N		7		K6		K6		K6				
Ammonia-N		K9		K9		K9		K9				
Total Organic Carbon	1000	K100	900	K100	700	700	300	K100				
Calcium	7000	5920	5790	5200	8720	7240	24000	6340				
Magnesium	3200	2720	2900	2530	3800	3110	3210	2730				
Sodium	44	8	39	9	49	9	126	25				
Iron	2960	112	2850	120	2500	120	3140	117				
Manganese	40	14.5	37	136	38	14.6	42	13.9				
Aluminum	725	24.9	677	24.1	732	20.8	626	20.6				
Titanium	233	K0.3	201	K0.3	201	K0.3	122	K0.3				
% Total Solids (105°C)	98.2		96.4		96.0		96.6					
Specific Gravity (20°C)	2.65		2.78		2.70		2.63					
Boron	K15	1.7	K15	1.4	K15	1.7	17	1.5				
Barium	K5	0.6	K5	1.7	K5	K0.3	7	0.4				
Cadmium	K1	0.5	K1	K0.5	K1	K0.5	K1	0.6				
Cobalt	K25	K1	K25	K1	K25	K1	K25	K1				
Chromium	K5	K0.3	K5	K0.3	K5	K0.3	K5	K0.3				
Copper	K1	K0.3	K1	K0.3	K1	K0.3	1.5	K0.3				
Molybdenum	K30	K2	K30	K2	K30	K2	K30	K2				
Lead	K5	K3	K5	K3	K5	K3	K5	K3				
Tin	K50	K3	K50	K3	K50	K3	54	K3				
Vanadium	16	K5	14	K5	35	K5	16	K5				
Yttrium	K2	K0.3	K2	K0.3	K2	K0.3	K2	K0.3				
Zinc	9	6.6	8	3.0	13	4.0	105	2.2				

*K indicates "less than".

ALCONA PROFILE 3 (mg/kg dry weight)*

Sample Depth (Number)	0-2"(001-5-1)		8-60"(001-5-2)									
Parameter	Total	Extr.	Total	Extr.	Total	Extr.	Total	Extr.	Total	Extr.	Total	Extr.
Total Phosphorus	110	79	600	140								
Orthophosphate-P		76		137								
Total Kjeldahl Nitrogen	320	42	180	23								
Nitrate/Nitrite-N		12		9								
Ammonia-N		10		10								
Total Organic Carbon	7900	300	5900	200								
Calcium	7640	6670	9420	6920								
Magnesium	3780	2920	4620	3400								
Sodium	55	21	24	21								
Iron	2620	139	2110	204								
Manganese	41	28.1	32	11.9								
Aluminum	842	58.2	918	53.4								
Titanium	154	0.8	166	1.1								
% Total Solids (105°C)	71.9		73.2									
Specific Gravity (20°C)	2.56		2.46									
Boron	K15	2.5	K15	2.3								
Barium	K5	3.2	K5	1.8								
Cadmium	K1	0.9	K1	0.9								
Cobalt	K25	K1	K25	K1								
Chromium	K5	K0.3	K5	K0.3								
Copper	1.5	0.4	1.5	K0.3								
Molybdenum	K30	K2	K30	K2								
Lead	K5	K3	K5	K3								
Tin	K50	K3	K50	K3								
Vanadium	16	K5	K10	K5								
Yttrium	K2	K0.3	K2	K0.3								
Zinc	11	6.9	12	7.8								

*K indicates "less than".

HURON COUNTY, MICHIGAN

PROFILE NUMBER: 1
LOCATION: Section 20, T. 15 N., R. 16 E.
SHORE TYPE: Erodible high bluff
DATE OF COLLECTION: June 20, 1975
COLLECTORS: University of Michigan Coastal Zone Laboratory
SUPPLEMENTAL INFORMATION: Samples 063-10-1 and 063-10-2 taken from face of bluff just east of other samples.

Sample Depth	Sample Number	Sample Description
0-6"(0-15.2 cm)	063-9-1	A1 horizon; dark grayish brown (10YR 4/2) silt loam; moderate medium granular structure; friable; mildly alkaline; gradual wavy boundary.
6-14"(15.2-35.6 cm)	063-9-2	B2 horizon; brown (10YR 5/3) silty clay loam; moderate medium angular blocky structure; firm; mildly alkaline; gradual wavy boundary.
14-60"(35.6-152.4 cm)	063-9-2	C horizon; pale brown (10YR 6/3) silt loam; with common medium distinct yellowish brown (10YR 5/6) mottles; weak medium subangular blocky structure; effervescent.
0-9"(0-22.9 cm)	063-10-1	C1 horizon; brown (10YR 5/3) silt loam; weak medium subangular blocky structure; friable; effervescent; gradual wavy boundary.
9-60"(22.9-152.4 cm)	063-10-2	C2 horizon; gray (10YR 5/1) and yellowish brown (10YR 5/6) stratified very fine sand and silt loam; weak thin platy structure; friable; effervescent.

PROFILE NUMBER: 2
LOCATION: Section 29, T. 18 N., R. 15 E.
SHORE TYPE: Erodible low plain
DATE OF COLLECTION: June 20, 1975
COLLECTORS: University of Michigan Coastal Zone Laboratory
SUPPLEMENTAL INFORMATION: Samples 063-8-1 and 063-8-2 taken from face of bluff just east of other samples.

Sample Depth	Sample Number	Sample Description
0-11"(0-27.9 cm)	063-7-1	A1 horizon; dark brown (7.5YR 3/2) gravelly sandy loam; moderate medium granular structure; friable; 75 percent gravel; mildly alkaline: clear wavy boundary.

PROFILE NUMBER: 2(continued)

Sample Depth	Sample Number	Sample Description
11-29"(27.9-73.7 cm)	063-7-2	B2 horizon; dark grayish brown (10YR 4/2) gravelly sandy loam; weak medium granular structure; friable; 75 percent gravel; mildly alkaline; clear wavy boundary.
29-60"(73.7-152.4 cm)	063-7-3	IIC horizon; brown (10YR 5/3) silt loam; weak medium angular blocky structure; firm; 40 percent gravel; effervescent.
0-9"(0-22.9 cm)	063-8-1	A1 horizon; dark brown (7.5YR 3/2) gravelly sandy loam; moderate medium granular structure; friable; 50 percent gravel; moderately alkaline; clear smooth boundary.
9-60"(22.9-152.4 cm)	063-8-2	IIC horizon; brown (10YR 5/3) silt loam; weak medium angular blocky structure; firm; effervescent.

PROFILE NUMBER: 3
LOCATION: Section 24, T. 19 N., R. 13 E.
SHORE TYPE: Non-erodible low bluff
DATE OF COLLECTION: June 20, 1975
COLLECTORS: University of Michigan Coastal Zone Laboratory
SUPPLEMENTAL INFORMATION: No significant bluff at this profile location.

Sample Depth	Sample Number	Sample Description
0-8"(0-20.3 cm)	063-6-1	A1 horizon; brown (10YR 5/3) sand; single grained; loose; mildly alkaline; gradual wavy boundary.
8-36"(20.3-91.4 cm)	063-6-2	C1 horizon; pale brown (10YR 6/3) sand; single grained; loose; mildly alkaline; gradual wavy boundary.
36-60"(91.4-152.4 cm)	063-6-3	C2 horizon; brown (10YR 5/3) gravelly sand; single grained; loose; effervescent.

PROFILE NUMBER: 4
LOCATION: Section 8, T. 18 N., R. 12 E.
SHORE TYPE: Low sand dune
DATE OF COLLECTION: June 20, 1975
COLLECTORS: University of Michigan Coastal Zone Laboratory
SUPPLEMENTAL INFORMATION: Sample 063-5-1 taken from face of bluff just north of other samples.

Sample Depth	Sample Number	Sample Description
0-6"(0-15.2 cm)	063-4-1	A1 horizon; pale brown (10YR 6/3) fine sand; weak medium granular structure; very friable; moderately alkaline; abrupt smooth boundary.
6-10"(15.2-25.4 cm)	063-4-2	IIC1 horizon; dark brown (10YR 3/3) loam; weak medium subangular blocky structure; friable; effervescent; abrupt smooth boundary.
10-60"(25.4-152.4 cm)	063-4-3	IIIC2 horizon; pale brown (10YR 6/3) sand; single grained; loose; effervescent.
0-60"(0-152.4 cm)	063-5-1	C1 horizon; brown (10YR 5/3) silt loam; with common medium distinct yellowish brown (10YR 5/6) mottles; weak medium subangular blocky structure; friable; effervescent.

PROFILE NUMBER: 5
LOCATION: Section 4, T. 17 N., R. 10 E.
SHORE TYPE: Erodible low bluff
DATE OF COLLECTION: June 19, 1975
COLLECTORS: University of Michigan Coastal Zone Laboratory
SUPPLEMENTAL INFORMATION: Sample 063-3-1 taken from face of bluff just west of other samples.

Sample Depth	Sample Number	Sample Description
0-8"(0-20.3 cm)	063-2-1	A1 horizon; light yellowish brown (10YR 6/4) sand; single grained; loose; neutral; gradual wavy boundary.
8-60"(20.3-152.4 cm)	063-2-3	C horizon; pale brown (10YR 6/3) sand; single grained; loose; mildly alkaline.
0-60"(0-152.4 cm)	063-3-1	C horizon; pale brown (10YR 6/3) sand; single grained; loose; effervescent.

PROFILE NUMBER: 6
LOCATION: Section 11, T. 16 N., R. 9 E.
SHORE TYPE: Wetland
DATE OF COLLECTION: June 19, 1975
COLLECTORS: University of Michigan Coastal Zone Laboratory
SUPPLEMENTAL INFORMATION: No bluff; water table at approximately 30 cm.

Sample Depth	Sample Number	Sample Description
0-8"(0-20.3 cm)	063-1-1	Al horizon; very dark brown (10YR 2/2) sandy loam; moderate medium granular structure; effervescent; clear wavy boundary.
8-32"(20.3-81.3 cm)	063-1-2	Cg horizon; gray (10YR 5/1) gravelly sand; single grained; loose; effervescent; gradual wavy boundary.
32-60"(81.3-152.4 cm)	063-1-3	IICg horizon; gray (10YR 6/1) clay loam; with common medium distinct yellowish brown (10YR 5/4) mottles; massive firm; effervescent.

HURON PROFILE 1 (mg/kg dry weight)*

Sample Depth (Number)	0-6"(063-9-1)		6-14"(063-9-2)		14-60"(063-9-3)		0-9"(063-10-1)		9-60"(063-10-2)			
Parameter	Total	Extr.	Total	Extr.	Total	Extr.	Total	Extr.	Total	Extr.	Total	Extr.
Total Phosphorus	240	38	310	12	230	26	310	18	350	40		
Orthophosphate-P		36		6		26		9		10		
Total Kjeldahl Nitrogen	1200	29	260	15	140	20	640	15	450	24		
Nitrate/Nitrite-N		23		6		22		9		8		
Ammonia-N		10		K9		14		10		13		
Total Organic Carbon	13000	400	1800	100	1200	K100	5200	200	18000	100		
Calcium	4480	5100	49600	42300	49900	37100	55800	40400	42600	33100		
Magnesium	3200	1110	17300	6190	16300	6250	18300	7780	23100	10200		
Sodium	K250	22.7	K250	26.5	K250	26.7	K250	29.8	K250	46.3		
Iron	10800	51.9	14300	4.1	8850	44.2	9890	14.1	12300	224		
Manganese	290	47.7	370	44.4	240	68.4	297	99.5	460	200		
Aluminum	8200	541	8980	K10	4080	123	4530	11.9	4120	58.3		
Titanium	92	1.0	140	K0.3	86	K0.3	75	0.3	109	0.8		
% Total Solids (105°C)	83.7		88.8		91.0		84.7		86.3			
Specific Gravity (20°C)	2.58		2.50		2.48		2.60		2.62			
Boron	K150	2.8	K150	3.4	K150	3.3	K150	4.0	K150	4.9		
Barium	52	31.5	58	10.5	K50	10.2	K50	12.9	K50	6.9		
Cadmium	K1	0.9	1	0.6	1	0.7	K1	0.8	1	1.3		
Cobalt	K250	K1	K250	K1	K250	1.2	K250	1.4	K250	1.9		
Chromium	K50	K0.3	K50	K0.3	K50	0.3	K50	0.5	K50	0.7		
Copper	K10	1.0	13	K0.3	K10	K0.3	K10	K0.3	K10	1.6		
Molybdenum	K300	K2	K300	2.4	K300	K2	K300	K2	K300	2.1		
Lead	16	4.2	32	K3	19	K3	23	K3	19	K3		
Tin	K500	K3	K500	6.8	K500	K3	K500	K3	K500	K3		
Vanadium	K100	K5	100	K5	K100	K5	K100	K5	K100	K5		
Yttrium	K10	1.5	K10	0.6	K10	1.8	K10	1.0	K10	2.2		
Zinc	K50	5.0	K50	0.5	K50	2.1	K50	2.1	50	4.2		

*K indicates "less than".

HURON PROFILE 2 (mg/kg dry weight)*

Sample Depth (Number)	0-11"(063-7-1)		11-29"(063-7-2)		29-60"(063-7-3)		0-9"(063-8-1)		9-60"(063-8-2)			
Parameter	Total	Extr.	Total	Extr.	Total	Extr.	Total	Extr.	Total	Extr.	Total	Extr.
Total Phosphorus	450	3	580	20	260	62	530	21	240	50		
Orthophosphate-P		3		19		57		18		50		
Total Kjeldahl Nitrogen	1800	21	1100	18	440	80	2100	22	380	14		
Nitrate/Nitrite-N		10		7		8		23		6		
Ammonia-N		K9		10		11		9		K9		
Total Organic Carbon	15000	K100	9600	200	3100	100	21000	300	3800	K100		
Calcium	3240	2080	2370	1450	16500	13800	3120	2570	8830	9120		
Magnesium	2600	209	2500	202	7180	3560	2470	397	5450	2270		
Sodium	K250	13	K250	10	290	29	K250	6	K250	1.5		
Iron	31500	63.3	27200	114	21600	372	23100	55.9	23700	2.94		
Manganese	1090	19.5	K150	17.4	390	146	527	59.3	410	80.2		
Aluminum	6860	448	5970	503	8170	435	5910	393	8680	449		
Titanium	27	0.4	30	0.7	44	1.2	25	0.5	46	0.7		
% Total Solids (105°C)	87.4		88.9		87.2		86.8		87.7			
Specific Gravity (20°C)	2.32		2.59		2.73		2.47		2.67			
Boron	K150	1.9	K150	1.8	K150	3.4	K150	2.4	K150	2.5		
Barium	K50	40.3	K50	29.8	K50	30.6	65	31.6	52	31.4		
Cadmium	K1	0.7	K1	0.7	K1	0.9	K1	0.7	K1	0.9		
Cobalt	K250	K1	K250	K1	K250	7.6	K250	K1	K250	2.3		
Chromium	K50	0.3	K50	K0.3	K50	0.6	K50	K0.3	K50	0.4		
Copper	12	0.4	K10	0.6	16	1.6	K10	0.9	15	0.9		
Molybdenum	K300	K2	K300	K2	K300	2.4	K300	K2	K300	K2		
Lead	30	K3	18	K3	13	10.9	26	4.0	14	K3		
Tin	K500	K3	K500	K3	K500	K3	K500	K3	K500	K3		
Vanadium	108	K5	K100	K5	K100	K5	K100	K5	K100	K5		
Yttrium	K20	0.5	K20	0.9	K20	2.8	K20	0.9	K10	2.1		
Zinc	89	6.4	K50	5.2	71	13.2	64	6.1	68	4.1		

*K indicates "less than".

HURON PROFILE 3 (mg/kg dry weight)*

Sample Depth (Number)	0-8"(063-6-1)		8-36"(063-6-2)		36-60"(063-6-3)							
Parameter	Total	Extr.	Total	Extr.	Total	Extr.	Total	Extr.	Total	Extr.	Total	Extr.
Total Phosphorus	65	28	18	15	25	20						
Orthophosphate-P		27		15		16						
Total Kjeldahl Nitrogen	130	10	44	19	76	18						
Nitrate/Nitrite-N		9		7		11						
Ammonia-N		K9		K9		11						
Total Organic Carbon	1400	K100	600	K100	K300	100						
Calcium	394	240	193	147	179	131						
Magnesium	403	32.1	301	20.7	240	16.1						
Sodium	K25	3	K25	8	K25	9						
Iron	3990	69.5	3600	24.8	3740	63.1						
Manganese	54	14.3	54	3.8	39	5.2						
Aluminum	1000	49.4	744	31.6	505	48.1						
Titanium	32	K0.3	22	K0.3	26	K1						
% Total Solids (105°C)	96.6		96.3		80.3							
Specific Gravity (20°C)	2.50		2.67		2.80							
Boron	K15	K1	K15	K1	K15	K2						
Barium	K5	2.1	6	2.5	K5	2.6						
Cadmium	K1	0.6	K1	0.7	K1	K1						
Cobalt	K25	K1	K25	K1	K25	K2						
Chromium	K5	K0.3	K5	K0.3	K5	K1						
Copper	1.2	K0.3	1.4	K0.3	1.6	K1						
Molybdenum	K30	K2	K30	K2	K30	K5						
Lead	K5	K3	K5	K3	K5	K5						
Tin	K50	K3	K50	K3	K50	K5						
Vanadium	15	K5	13	K5	14	K10						
Yttrium	K2	K0.3	K2	K0.3	K2	K1						
Zinc	10	3.0	8	1.7	5	2.2						

*K indicates "less than".

HURON PROFILE 4 (mg/kg dry weight)*

Sample Depth (Number)	0-6"(063-4-1)		6-10"(063-4-2)		10-60"(063-4-3)		0-60"(063-5-1)					
Parameter	Total	Extr.	Total	Extr.	Total	Extr.	Total	Extr.	Total	Extr.	Total	Extr.
Total Phosphorus	80	42	250	120	29	24	210	90				
Orthophosphate-P		41		110		23		89				
Total Kjeldahl Nitrogen	61	10	750	31	41	K10	500	16				
Nitrate/Nitrite-N		12		11		K6		K6				
Ammonia-N		K9		12		K9		K9				
Total Organic Carbon	1000	300	7000	200	K300	K100	5500	200				
Calcium	2210	2480	29800	30500	2030	611	32900	36100				
Magnesium	1380	1110	12800	5800	1100	254	16800	8300				
Sodium	K25	8	K250	29	K250	8	K250	40				
Iron	2260	54.4	8940	45.1	5910	22.0	9710	100.3				
Manganese	32	16.3	190	76	K150	4.4	230	77				
Aluminum	499	45.1	6330	348	558	20.8	6450	443				
Titanium	40	K0.3	103	0.4	380	K0.3	109	2.7				
% Total Solids (105°C)	96.4		87.0		98.4		89.9					
Specific Gravity (20°C)	2.61		2.54		2.76		2.67					
Boron	K15	1.8	K150	4.5	K150	K1	K150	4.7				
Barium	K5	2.4	K50	18.5	K50	0.5	K50	24.2				
Cadmium	K1	K0.5	K1	0.9	K1	K0.5	K1	0.6				
Cobalt	K25	K1	K250	1.5	K250	K1	K250	1.4				
Chromium	K5	K0.3	K50	0.8	K50	K0.3	K50	0.4				
Copper	K1	K0.3	10	0.6	K10	K0.3	10	0.7				
Molybdenum	K30	K2	K300	K2	K300	K2	K300	K2				
Lead	K5	3.6	15	K3	K5	K3	16	K3				
Tin	K50	K3	K500	4.4	K500	K3	K500	10.0				
Vanadium	11	K5	K100	K5	K100	K5	K100	K5				
Yttrium	K2	K0.3	K20	2.0	K20	K0.3	K20	2.9				
Zinc	7	5.2	K50	2.5	K50	2.0	K50	4.8				

*K indicates "less than".

HURON PROFILE 5 (mg/kg dry weight)*

Sample Depth (Number)	0-8"(063-2-1)		8-60"(063-2-2)		0-60"(063-3-1)							
Parameter	Total	Extr.	Total	Extr.	Total	Extr.	Total	Extr.	Total	Extr.	Total	Extr.
Total Phosphorus	50	31	64	22	45	23						
Orthophosphate-P		30		22		23						
Total Kjeldahl Nitrogen	110	29	23	14	42	28						
Nitrate/Nitrite-N		38		K6		10						
Ammonia-N		13		K9		20						
Total Organic Carbon	1200	K100	1000	100	600	K100						
Calcium	874	824	785	626	907	708						
Magnesium	530	243	522	225	543	283						
Sodium	K25	6	K25	8	K25	9						
Iron	1910	22.8	1880	22.9	1780	20.5						
Manganese	24	5.6	23	6.2	19	3.8						
Aluminum	451	26.2	386	24.9	310	18.0						
Titanium	82	K0.3	36	K0.3	36	K0.3						
% Total Solids (105°C)	95.2		96.4		96.1							
Specific Gravity (20°C)	2.57		2.65		2.78							
Boron	K15	1.1	K15	1.1	K15	K1						
Barium	K5	0.7	K5	0.8	K5	0.6						
Cadmium	K1	0.5	K1	0.5	K1	K0.5						
Cobalt	K25	K1	K25	K1	K25	K1						
Chromium	K5	K0.3	K5	K0.3	K5	K0.3						
Copper	K1	K0.3	K1	K0.3	K1	K0.3						
Molybdenum	K30	K2	K30	K2	K30	K2						
Lead	K5	K3	K5	K3	K5	K3						
Tin	K50	K3	K50	K3	K50	K3						
Vanadium	K10	K5	K10	K5	K10	K5						
Yttrium	K2	K0.3	K2	K0.3	K2	K0.3						
Zinc	7	2.9	K5	2.8	K5	33						

*K indicates "less than".

HURON PROFILE 6 (mg/kg dry weight)*

Sample Depth (Number)	0-8"(063-1-1)		8-32"(063-1-2)		32-60"(063-1-3)							
Parameter	Total	Extr.	Total	Extr.	Total	Extr.	Total	Extr.	Total	Extr.	Total	Extr.
Total Phosphorus	160	43	69	31	K23	14						
Orthophosphate-P		43		31		2						
Total Kjeldahl Nitrogen	2200	57	110	28	K69	14						
Nitrate/Nitrite-N		28		7		K6						
Ammonia-N		13		14		K9						
Total Organic Carbon	18000	400	800	200	1500	K100						
Calcium	21400	24600	18100	26700	64100	52600						
Magnesium	4280	3880	4640	3730	18300	8260						
Sodium	55	34	59	37	K250	39						
Iron	2880	193	2220	132	7000	51						
Manganese	66	53	38	28	184	102						
Aluminum	1070	155	766	85	4200	25.6						
Titanium	34	0.9	57	0.8	111	0.6						
% Total Solids (105°C)	70.5		81.5		89.4							
Specific Gravity (20°C)	2.45		2.61		2.75							
Boron	16	5.1	K15	2.5	K150	3.7						
Barium	14	11.1	7	4.3	K50	10.6						
Cadmium	K1	K1	K1	K1	1	0.8						
Cobalt	K25	K2	K25	K2	K250	K1						
Chromium	6	K1	K5	K1	K50	K0.3						
Copper	4	1.2	2	K1	K10	K0.3						
Molybdenum	K30	K5	K30	K5	K300	2.6						
Lead	39	24	K5	K5	19	K3						
Tin	52	K5	K50	K5	K500	14						
Vanadium	29	K10	26	K10	K100	K5						
Yttrium	K2	K1	K2	K1	K20	1.0						
Zinc	43	32	7	2.1	K50	2.1						

*K indicates "less than".

OSWEGO COUNTY, NEW YORK

PROFILE NUMBER: 1
LOCATION: Mileage marker 123.515; approximately 80 feet north of a limestone block revetment near north end of Sandy Point Beach; 2.325 inches north of the edge of air photo mosaic 11-35-4372432.
SHORE TYPE: Low sand dune lakeward/wetlands landward
DATE OF COLLECTION: July 2, 1975
COLLECTORS: St. Lawrence-Eastern Ontario Commission
SUPPLEMENTAL INFORMATION: Despite the shore type designation assigned by the Army Corps of Engineers, the sample collectors described this profile as a high (approximately 14 meters) dune with beach (approximately 12 meters wide). Bluff protected by beach and offshore sand bar.

Sample Depth	Sample Number	Sample Description
6"(15.2 cm)	NY-1-1	Dune sand; fine grained and well sorted; roots and fine grained organic matter; sand cross bedded but difficult to detect due to ferromagnesium-rich mineral grains.
11'(335.2 cm)	NY-1-2	Dune sand; fine grained and well sorted.

PROFILE NUMBER: 2
LOCATION: Mileage marker 125.347, at Rainbow Shores; profile taken near a tree stump on the back beach, about 60 feet south of a small dirt road located on air photo mosaic 11-35-4312425; 2.46 inches north of the southern edge.
SHORE TYPE: Low sand dune lakeward/wetland landward
DATE OF COLLECTION: July 2, 1975
COLLECTORS: St. Lawrence-Eastern Ontario Commission
SUPPLEMENTAL INFORMATION: The 5.5 meter bluff is protected by a gravel beach that is about 10 1/2 meters wide and rises to a height of about 1.7 meters at the toe of the bluff. The stratographic units are very variable and change suddenly when traced from north to south. 9 meters south of the profile, the entire bluff consists only of a yellow-brown sand (a channel fill deposit). The first meter consists of yellow-brown silt of very fine grained sand. The next 0.7 meter consists of moderately sorted, partially indurated cobbles, with a sandry matrix. The next approximately .4 meters consists of loose, brown, pebbly clayey sand. The next approximately 2 meters consists of gray silty clay or clay silt.

PROFILE NUMBER: 2(continued)

Sample Depth	Sample Number	Sample Description
0"	NY-2-1	A1 horizon
10"(25.4 cm)	NY-2-2	B horizon
21"(53.3 cm)	NY-2-3	IIB horizon
42"(106.7 cm)	NY-2-4	IIC horizon
78"(198.1 cm)	NY-2-5	IIIC horizon

PROFILE NUMBER: 3
LOCATION: Mileage marker 135.88, at Hickory Grove; located on air photo mosaic 11-35-392 to 387, 2.71 inches east of the east bank of Catfish Creek.
SHORE TYPE: Erodible low bluff
DATE OF COLLECTION: July 2, 1975
COLLECTORS: St. Lawrence-Eastern Ontario Commission
SUPPLEMENTAL INFORMATION: The bluff, which is approximately 6 meters high, is protected by a gravel beach that is about 4.5 meters wide and which rises to a height of about 1 meter above lake level. The gravel consists of very poorly sorted pebbles, cobbles, and boulders. The first 3 meters of the bluff consist of weathered, brownish-gray till, containing several thin lenses of sand overlying medium gray till. Numerous fresh slump scars were found along the bluff.

Sample Depth	Sample Number	Sample Description
0"	NY-3-1	A1 horizon
16"(40.6 cm)	NY-3-2	B horizon
31"(78.7 cm)	NY-3-3	B3 horizon
71"(180.3 cm)	NY-3-4	C horizon
142"(360.7 cm)	NY-3-5	C2 horizon

PROFILE NUMBER: 4
LOCATION: Mileage marker 149.48; located on Oswego campus of the State University College, 40 feet east of Johnson Hall. The profile lies 18.3 feet from the cliff edge (0.675 inches east of western edge of air photo mosaic 11-35-3412336).
SHORE TYPE: Erodible low bluff

PROFILE NUMBER: 4(continued)
DATE OF COLLECTION: July 2, 1975
COLLECTORS: St. Lawrence-Eastern Ontario Commission
SUPPLEMENTAL INFORMATION: The bluff is about 8 meters high and at the toe of the bluff is a 5-6 meter wide beach of moderately sorted large cobbles. Some small boulders are concentrated at the shoreline. The shore is protected somewhat by a 15-20 meter wide subaqueous rock platform of the resistent Oswego sandstone that lies east of the site. The water depth is generally less than 0.1 meters on the platform. The bluff material is a medium gray sandy till which contains about 25% stones and weathers to a brownish color. The upper 0.6-0.9 meter is badly weathered. Active slumping has caused this bluff to recede at a rate of about .6 meters per year since 1972. Prior to that, the bluff was fairly stable and receded at a rate of less than 0.1 meters per year.

Sample Depth	Sample Number	Sample Description
0"	NY-4-1	A1 horizon
37"(94 cm)	NY-4-2	B horizon
67"(170.2 cm)	NY-4-3	C horizon
180"(457.2 cm)	NY-4-4	C2 horizon

OSWEGO PROFILE 1 (mg/kg dry weight)*

Sample Depth (Number)	11'(NY-1-2)		6"(NY-1-1)									
Parameter	Total	Extr.	Total	Extr.	Total	Extr.	Total	Extr.	Total	Extr.	Total	Extr.
Total Phosphorus	150	110	180	180								
Orthophosphate-P		110		176								
Total Kjeldahl Nitrogen	K38	16	140	15								
Nitrate/Nitrite-N		K6		6								
Ammonia-N		K9		K9								
Total Organic Carbon	K300	K100	2000	200								
Calcium	530	348	1120	666								
Magnesium	540	46.2	560	48.6								
Sodium	K250	5.4	48	8.5								
Iron	2830	30.5	4170	32.7								
Manganese	K150	6.1	72	23.5								
Aluminum	810	34.8	902	58.1								
Titanium	36	K0.3	289	K0.3								
% Total Solids (105°C)	96.6		99.8									
Specific Gravity (20°C)	2.74		2.22									
Boron	K150	K1	K15	K1								
Barium	K50	1.6	K5	2.0								
Cadmium	K1	K0.5	K1	0.6								
Cobalt	K250	K1	K25	K1								
Chromium	K50	K0.3	K5	K0.3								
Copper	K10	K0.3	K1	K0.3								
Molybdenum	K300	K2	K30	K2								
Lead	K5	K3	K5	K3								
Tin	K500	K3	K50	K3								
Vanadium	K100	K5	11	K5								
Yttrium	K20	0.7	K2	0.8								
Zinc	K50	3.0	11	4.8								

*K indicates "less than".

OSWEGO PROFILE 2 (mg/kg dry weight)*

Sample Depth (Number)	0"(NY-2-1)		10"(NY-2-2)		21"(NY-2-3)		42"(NY-2-4)		78"(NY-2-5)			
Parameter	Total	Extr.	Total	Extr.	Total	Extr.	Total	Extr.	Total	Extr.	Total	Extr.
Total Phosphorus	580	120	320	53	78	3	210	110	400	360		
Orthophosphate-P		119		52		3		106		380		
Total Kjeldahl Nitrogen	1400	33	460	30	59	K10	60	K10	55	18		
Nitrate/Nitrite-N		K6		K6		K6		K6		K6		
Ammonia-N		11		10		K9		K9		K9		
Total Organic Carbon	18000	600	7800	500	500	100	K300	K100	K300	K100		
Calcium	1070	963	380	296	190	123	610	432	14200	10300		
Magnesium	750	96	1560	35.7	3260	27.8	2610	45.3	2660	2150		
Sodium	K250	6.0	K250	1.4	K250	3.0	K250	4.9	K250	18.0		
Iron	9540	94	12100	84	17700	25.3	13700	45.3	12800	172		
Manganese	271	65.8	306	12.0	1340	11.0	470	6.3	350	107		
Aluminum	4520	657	5360	624	6620	144	4980	277	4270	234		
Titanium	108	1.4	29	1.2	30	0.3	66	K0.3	210	K1		
% Total Solids (105°C)	97.6		95.4		97.3		92.6		86.3			
Specific Gravity (20°C)	1.95		2.27		2.51		2.65		2.72			
Boron	K150	K1	K150	K1	K150	K1	K150	K1	K150	K2		
Barium	K50	15.9	K50	10.1	K50	9.7	K50	8.2	K50	15.1		
Cadmium	K1	0.6	K1	0.6	K1	K0.5	K1	0.6	K1	K1		
Cobalt	K250	K1	K250	K1	K250	K1	K250	K1	K250	K2		
Chromium	K50	K0.3	K50	K0.3	K50	K0.3	K50	K0.3	K50	K1		
Copper	K10	0.5	10	3.5	39	0.8	23	0.4	10	K1		
Molybdenum	K300	2.1	K300	K2	K300	K2	K300	K2	K300	K5		
Lead	10	3.9	7	K3	5	K3	K5	K3	K5	K10		
Tin	K500	K3	K500	K3	K500	K3	K500	K3	K500	K10		
Vanadium	K100	K5	K100	K5	K100	K5	K100	K5	K100	K10		
Yttrium	K20	K0.3	K20	1.2	K20	4.6	K20	11.2	K20	4.7		
Zinc	K50	10.0	K50	5.6	K50	2.3	K50	1.6	K50	4.8		

*K indicates "less than".

OSWEGO PROFILE 3 (mg/kg dry weight)*

Sample Depth (Number)	0"(NY-3-1)		16"(NY-3-2)		31"(NY-3-3)		142"(NY-3-5)					
Parameter	Total	Extr.	Total	Extr.	Total	Extr.	Total	Extr.	Total	Extr.	Total	Extr.
Total Phosphorus	450	42	350	150	450	340	690	380				
Orthophosphate-P		34		148		330		390				
Total Kjeldahl Nitrogen	1100	28	220	34	85	12	430	10				
Nitrate/Nitrite-N		K6		6		K6		K6				
Ammonia-N		12		10		K9		9				
Total Organic Carbon	13000	300	1000	100	300	K100	1800	K100				
Calcium	1580	2080	1330	1430	1840	2290	18600	10000				
Magnesium	2390	431	4270	198	3580	324	12300	2140				
Sodium	K250	13.8	K250	17.3	K250	43.6	K250	28.4				
Iron	15800	87	22300	120	18200	360	32400	851				
Manganese	270	14.7	569	14.0	595	54.2	690	255				
Aluminum	10200	470	9480	391	6160	527	14300	177				
Titanium	60	0.6	75	0.4	118	1.4	74	2.5				
% Total Solids (105°C)	94.7		89.8		88.1		88.7					
Specific Gravity (20°C)	2.35		2.59		2.63		2.75					
Boron	K150	K1	K150	K1	K150	K2	K150	3.4				
Barium	K50	17.8	K50	19.4	K50	18.8	K50	6.2				
Cadmium	K1	0.7	K1	0.6	K1	K1	K1	1.1				
Cobalt	K250	K1	K250	K1	K250	K2	K250	3.0				
Chromium	K50	K0.3	K50	K0.3	K50	K1	K50	K0.3				
Copper	K10	0.9	23	0.9	K10	1.6	26	6.0				
Molybdenum	K300	K2	K300	K2	K300	K5	K300	2.9				
Lead	12	K3	K5	K3	K5	K10	9	4.4				
Tin	K500	K3	K500	K3	K500	K10	K500	10.8				
Vanadium	K100	K5	K100	K5	K100	K10	K100	K5				
Yttrium	K20	0.4	K20	4.3	K20	5.7	K20	5.1				
Zinc	57	6.9	K50	16.4	K50	5.2	60	2.6				

*K indicates "less than".

OSWEGO PROFILE 4 (mg/kg dry weight)*

Sample Depth (Number)	0"(NY-4-1)		37"(NY-4-2)		67"(NY-4-3)		180"(NY-4-4)					
Parameter	Total	Extr.	Total	Extr.	Total	Extr.	Total	Extr.	Total	Extr.	Total	Extr.
Total Phosphorus	370	32	470	230	490	250	440	290				
Orthophosphate-P		29		230		250		275				
Total Kjeldahl Nitrogen	1400	35	160	K10	85	26	260	15				
Nitrate/Nitrite-N		K6		K6		K6		7				
Ammonia-N		14		K9		10		10				
Total Organic Carbon	17000	400	1800	K100	K300	K100	800	K100				
Calcium	1400	1040	28700	21900	35900	43100	37900	37100				
Magnesium	2600	73.8	7700	2880	9040	3690	10200	4170				
Sodium	K250	13.2	K250	24.5	K250	38.2	K250	35.1				
Iron	20200	67.5	13800	156	14700	229	14200	532				
Manganese	296	11.4	354	108	365	152	380	244				
Aluminum	11300	659	4170	189	4330	180	4920	129				
Titanium	97	0.6	165	1.6	367	4.0	186	3.7				
% Total Solids (105°C)	94.8		90.1		91.7		91.9					
Specific Gravity (20°C)	2.20		2.84		2.81		2.81					
Boron	K150	K1	K150	3.0	K150	2.2	K150	2.9				
Barium	K50	22.8	K50	10.0	K50	8.0	K50	4.2				
Cadmium	K1	1.2	K1	0.9	K1	0.8	K1	0.7				
Cobalt	K250	K1	K250	K1	K250	1.4	K250	2.2				
Chromium	K50	K0.3	K50	K0.3	K50	0.4	K50	0.6				
Copper	13	1.6	12	0.4	12	0.9	10	1.9				
Molybdenum	K300	K2	K300	4.0	K300	K2	K300	K2				
Lead	52	24.1	10	3.8	12	K3	12	K3				
Tin	K500	K3	K500	21.7	K500	3.8	K500	K3				
Vanadium	K100	K5	K100	K5	K100	K5	K100	K5				
Yttrium	K20	1.3	K20	4.3	K20	4.7	K20	5.4				
Zinc	91	15.6	K50	3.1	K50	3.1	K50	2.9				

*K indicates "less than".

APPENDIX

B.

PARTICLE SIZE ANALYSIS

APPENDIX B

Particle Size Analysis (microns)

Profile Number	Sample Number	Sieve Test % > 850	% 850-250	% 250-75	% 75-20	Sedimentation Cylinder % 5	% 5-40	% > 40	Soil Type*
St. Louis Co. Minnesota (#3, Lake Superior)									
1	SL-1-1					35	29	36	L
1	SL-1-2					50	18	32	C
1	SL-1-3					62	26	12	C
1	SL-1-4					46	23	31	C
1	SL-1-5					13	11	76	L
2	SL-2-1					32	35	33	L
2	SL-2-2					48	32	20	C
2	SL-2-3					58	20	22	C
2	SL-2-4					19	31	50	L
2	SL-2-5	46	27	19	8				S
3	SL-3-1					8	14	78	L
3	SL-3-2					49	10	41	C
3	SL-3-3					58	18	24	C
3	SL-3-4					27	49	24	L
3	SL-3-5					25	28	47	L
4	SL-4-1	K1	16	84	K1				S
4	SL-4-2	K1	55	45	K1				S
5	SL-5-1	K1	82	18	K1				S
5	SL-5-2	K1	85	15	K1				S
6	SL-6-1	11	33	51	5				S
6	SL-6-2	6	32	53	9				S
7	SL-7-1					84	9	7	C
7	SL-7-2					55	28	17	C
Douglas Co. Wisconsin (#4, Lake Superior)									
1	D-1-1					28	22	50	L
1	D-1-2					56	17	27	C
2	D-2-1					58	17	25	C
2	D-2-2					64	16	20	C
3	D-3-1					37	25	38	L
3	D-3-2					75	9	16	C
4	D-4-1					5	18	77	S
4	D-4-2					53	6	41	C
Chippewa Co. Michigan (#16, Lake Superior)									
1	033-4-1	K1	76	24	K1				S
1	033-4-2	K1	84	16	K1				S
1	033-4-3	K1	89	11	K1				S
1	033-4-4	K1	72	28	K1				S
2	033-3-1	6	53	39	2				S
2	033-3-2	K1	60	40	K1				S
2	033-3-3	K1	55	44	1				S
2	033-3-4	K1	4	96	K1				S
2	033-3-5	K1	5	94	1				S
2	033-3-6	K1	5	95	K1				S
2	033-3-7	K1	3	95	2				S

3	033-2-1	4	94	2	K1				S
3	033-2-2	7	92	1	K1				S

Brown Co. Wisconsin (#37, Lake Michigan)

2	B-2-1	40	40	17	3				S
2	B-2-2	8	40	52	K1				S
2	B-2-3	3	86	10	1				S
3	B-3-1	43	47	9	1				S
3	B-3-2					45	17	38	C
4	B-4-1	K1	22	78	K1				S
5	B-5-1	K1	98	2	K1				S
5	B-5-2	1	97	2	K1				S
6	B-6-1	1	79	20	K1				S
6	B-6-2					42	21	37	C

Racine Co. Wisconsin (#44, Lake Michigan)

1	R-1-1					16	23	61	L
1	R-1-2					49	28	23	C
1	R-1-3					32	22	46	L
2	R-2-1					19	21	60	L
2	R-2-2	12	6	74	8				S
2	R-2-3					40	37	23	L
3	R-3-1	4	85	10	1				S
3	R-3-2	K1	94	6	K1				S
4	R-4-1					15	14	71	L
4	R-4-2	24	22	22	32				S
4	R-4-3					28	33	39	L
5	R-5-1	28	28	40	4				S
5	R-5-2					11	19	70	L
5	R-5-3					33	34	33	L

Muskegon Co. Michigan (#25, Lake Michigan)

1	121-1-1	K1	73	27	K1				S
1	121-1-2	K1	62	38	K1				S
1	121-1-3	K1	68	32	K1				S
1	121-1-4	K1	54	46	K1				S
1	121-2-1	K1	55	45	K1				S
2	121-3-1	K1	76	24	K1				S
2	121-3-2	K1	70	30	K1				S
2	121-3-3					37	20	43	L
2	121-3-4	K1	67	33	K1				S
2	121-4-1	K1	50	50	K1				S
2	121-4-2	K1	33	62	5				S
2	121-4-3	23	72	5	K1				S
3	121-5-1	K1	71	29	K1				S
3	121-5-2	K1	79	21	K1				S
3	121-5-3	K1	86	14	K1				S
3	121-6-1	K1	88	12	K1				S
4	121-7-1	K1	70	30	K1				S
4	121-7-2	K1	54	46	K1				S
4	121-8-1	K1	85	15	K1				S

Manistee Co. Michigan (#28, Lake Michigan)

1	101-1-1					27	17	56	L
1	101-1-2					26	10	64	L
1	101-1-3					20	25	55	L
1	101-1-4					29	21	50	L
1	101-2-1					34	17	49	L
1	101-2-2					17	22	61	L
2	101-3-1	1	96	3	K1				S
2	101-3-2	K1	99	1	K1				S
2	101-4-1	1	94	5	K1				S
2	101-4-2	6	93	1	K1				S
3	101-5-1	K1	93	7	K1				S
3	101-5-2					15	11	74	L
3	101-5-3					59	26	15	C
3	101-5-4	K1	99	10	K1				S
3	101-6-1	2	97	1	K1				S

Schoolcraft Co. Michigan (#18, Lake Michigan)

1	153-1-1	K1	15	85	K1				S
1	153-1-2	K1	17	83	K1				S
1	153-1-3	K1	22	77	1				S
2	153-2-1	K1	11	89	K1				S
2	153-2-2	K1	18	82	K1				S
3	153-3-5		No Data						
3	153-3-6	2	75	23	K1				S
3	153-3-7	K1	56	44	K1				S
4	153-4-2		No Data						
4	153-4-3	K1	22	78	K1				S
4	153-4-4	2	21	77	K1				S
4	153-4-5	K1	32	68	K1				S
5	153-5-1	K1	58	42	K1				S
5	153-5-2	K1	46	54	K1				S
5	153-5-3	K1	37	63	K1				S

Alcona Co. Michigan (#54, Lake Huron)

1	001-1-1	K1	64	36	K1				S
1	001-1-2	K1	65	35	K1				S
1	001-2-1	K1	66	34	K1				S
2	001-3-1	K1	72	28	K1				S
2	001-3-2	K1	83	17	K1				S
2	001-3-3	K1	79	21	K1				S
2	001-4-1	K1	90	10	K1				S
3	001-5-1	K1	8	91	1				S
3	001-5-2	K1	11	88	1				S

Huron Co. Michigan (#59, Lake Huron)

1	063-9-1					16	18	66	L
1	063-9-2					25	21	54	L
1	063-9-3	52	28	20	K1				S
1	063-10-1					15	13	72	L
1	063-10-2					14	44	42	L
2	063-7-1	78	15	6	1				S
2	063-7-2					7	26	67	L
2	063-7-3					12	28	60	L
2	063-8-1	45	44	9	2				S
2	063-8-2					14	16	70	L
3	063-6-1	1	62	37	K1				S
3	063-6-2	1	75	24	K1				S
3	063-6-3	1	85	14	K1				S
4	063-4-1	K1	24	75	1				S
4	063-4-2					23	13	64	L
4	063-4-3	K1	76	24	K1				S
4	063-5-1					20	12	68	L
5	063-2-1	K1	43	57	K1				S
5	063-2-2	K1	43	57	K1				S
5	063-3-1	1	48	51	K1				S
6	063-1-1	7	73	19	1				S
6	063-1-2	7	52	38	3				S
6	063-1-3					17	10	73	L

Oswego Co. New York (#81, Lake Ontario)

1	NY-1-2	K1	8	92	K1				S
1	NY-1-1	K1	12	88	K1				S
2	NY-2-1	1	7	85	7				S
2	NY-2-2	10	12	73	5				S
2	NY-2-3	27	33	37	3				S
2	NY-2-4	7	66	26	1				S
2	NY-2-5	12	20	44	24				S
3	NY-3-1					11	20	69	L
3	NY-3-2					7	19	74	L
3	NY-3-3	30	17	28	25				S
3	NY-3-5					33	21	46	L
4	NY-4-1					11	13	76	L
4	NY-4-2	26	26	34	14				S
4	NY-4-3					4	16	80	S
4	NY-4-4					16	8	76	L

K-Less than value shown
*S-Sand
L-Loam
C-Clay